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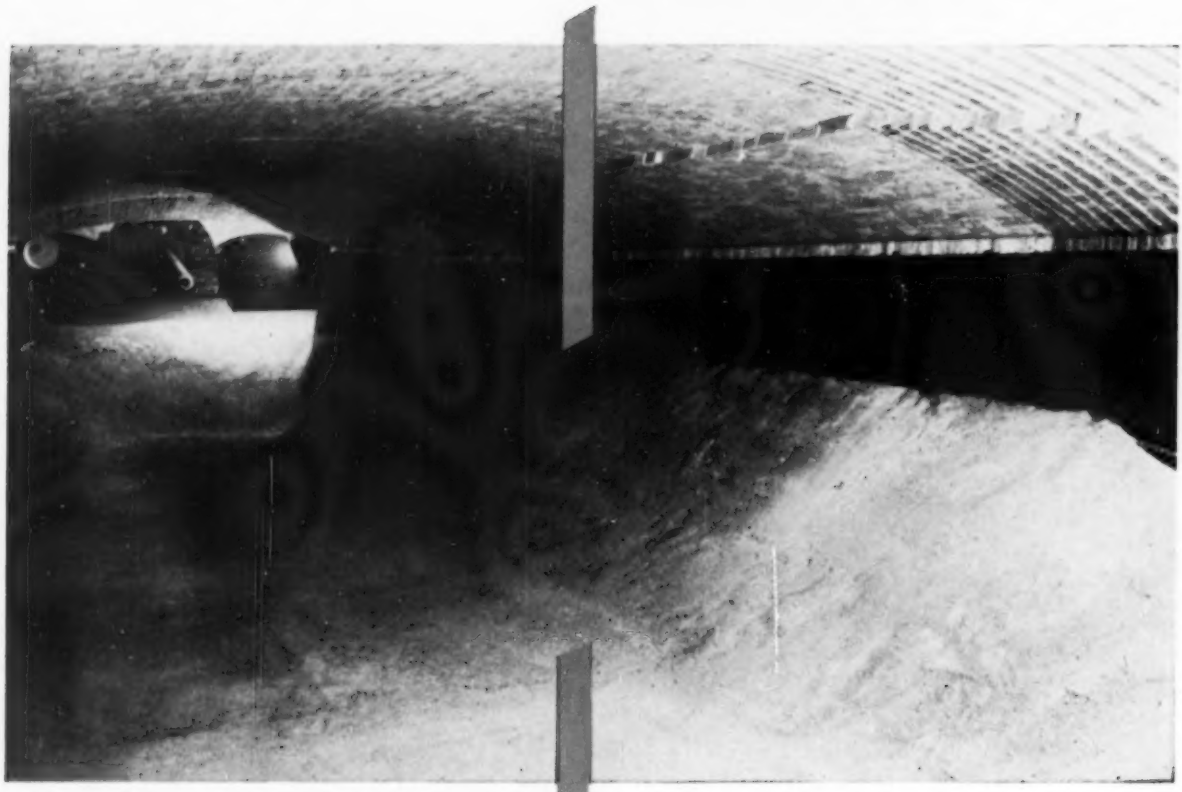
June 1954



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COVER

June is the traditional month for weddings and graduations, both of which are educational experiences. Artist Harry Brocke illustrates an aspect of one of these events on this month's cover. For more information on this subject turn to p. 728. (Electron micrograph of pearlite in steel [10,000X] and rotating crystal diffraction film of a germanium single crystal are courtesy of RCA and North American Philips Co., Inc., respectively.)

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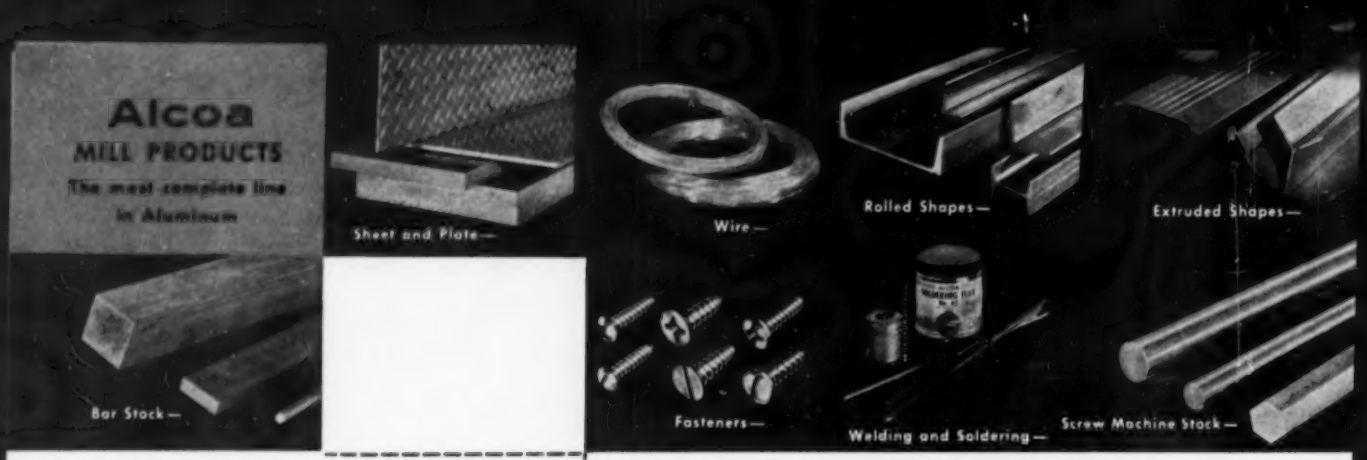

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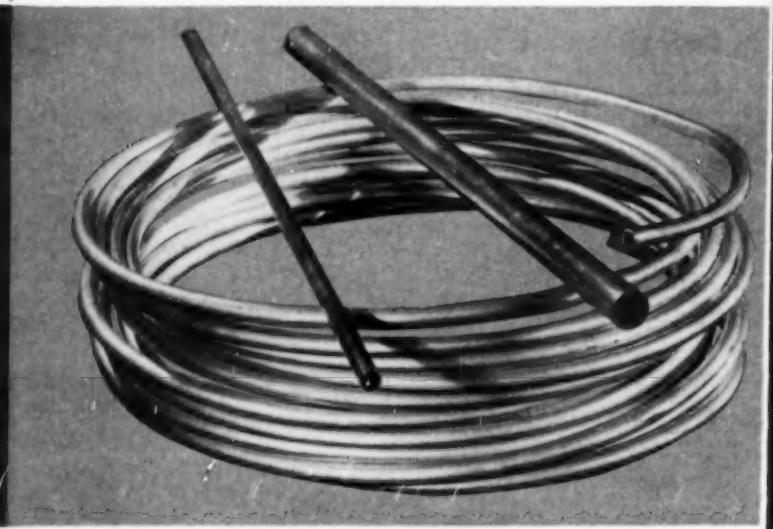

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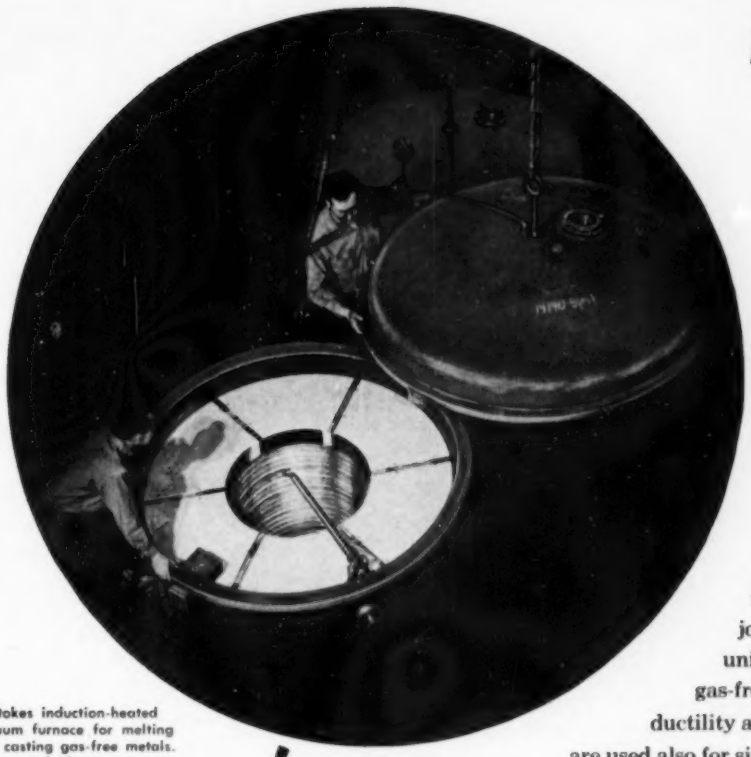

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Chemistry of the Defect Solid States, by A. L. G. Rees. *John Wiley & Sons, Inc.* $2.00, 136 pp., 1954.—The book is designed to stimulate research. In writing the book no attempt has been made to discuss solid state reactions in any detail. Rather, an attempt has been made to outline in general terms the part played in these processes by defects. Of the theoretical foundations, statistical thermodynamics has been considered to be the most relevant to the chemical problem so has been treated in some detail; the quantum mechanics of defect solids can be discussed adequately without mathematical complication, the author feels.

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Copper, edited by Allison Butts. *Reinhold Publishing Corp.* $20.00, 936 pp., 1954.—The book is subtitled *The Science and Technology of the Metal, Its Alloys and Compounds.* Almost every phase of the chemistry and metallurgy of copper, its alloys and compounds, is covered. The 46 chapters are each written by a specialist in his field. They cover all important fundamental principles, latest practices in the industry, and many of the less well-known applications of copper.

Symposium on Light Microscopy. *American Society for Testing Materials.* $2.50, 132 pp., 1954—Papers in this symposium, presented at the 55th annual meeting of the American Society for Testing Materials, are representative of the applications of the microscope as a technical tool in a number of fields. The book covers: The Methods of Microscopy by Clyde W. Mason; Apparatus for Microscopy by H. W. Zieler; Some Applications of Light Microscopy in the Study of Textile Materials by V. W. Tripp; Polarized Light Microscopy and Supplementary Techniques by W. C. McCrone; Applications of Light Microscopy in Concrete Research by Katherine Mather; The Microscopal Examination of Metallic Specimens by J. R. Vilella; Resinography, the Microscopy of Resins and Their Plastics by T. G. Rochow; and Methods of Particle-Size Analysis by R. P. Loveland.

The Physical Chemistry of Copper Smelting, by R. W. Ruddle. *Institution of Mining and Metallurgy.* 156 pp., 1953—The first chapter of this book is devoted to fundamentals of modern smelting processes. The next two chapters deal with more theoretical aspects of the constitution of mattes and slags. The remaining four chapters discuss magnetic formation, copper losses during smelting, recovery of sulphur from the smokes produced during the smelting, and the elimination of impurities.

Influence of Temperature and Rate of Strain on the Properties of Metals in Torsion, by Clyde E. Work and Thomas J. Dolan. *University of Illinois.* $1.00, 109 pp., 1953.—The bulletin is a report of an experimental work to determine the effect of temperature and rate of strain on the strength, ductility, and energy absorbing capacity of seven different structural metals under torsion. Torque, angle of twist, and time were continuously recorded and the torsional properties determined. Detailed results are presented in three dimensional charts and analyzed in terms of the mechanisms altering the material behavior.

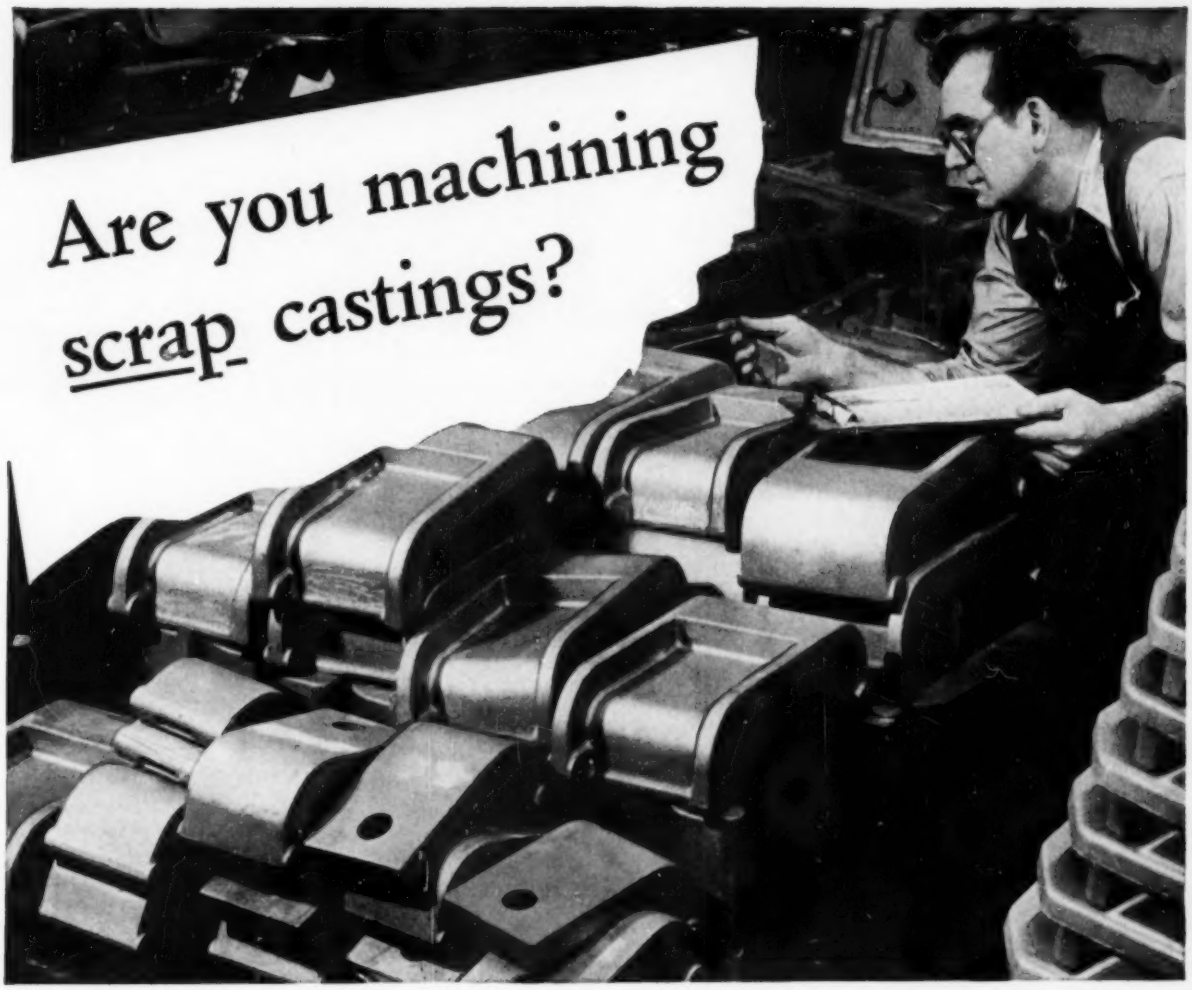
The Spectrum of Steel, by John Convey and J. K. Hurwitz. *Dept. of Mines and Technical Surveys, Mines Branch,* Ottawa, Canada. $1.00, 55 pp., 1954.—Fundamental and practical information concerning the ultraviolet spectrum of steel alloys is tabulated. Subtitle of the volume is *A Table for the Selection of Homologous Spectal Lines.*

Industrial Uses for Germanium Crystals, Sylvania Electric Products Inc. 25¢, 42 pp., 1954.—Realizing that there are many applications of germanium crystals which are of particular use to industry and of only secondary interest to the communications worker, the new booklet is devoted entirely to industrial applications. The four main chapters in the booklet cover: Relays and relay applications; timing circuits; power supply applications; and applications to industrial instrumentation.

Comprehensive Inorganic Chemistry, Vol. II, by J. W. Laist. *D. Van Nostrand Co., Inc.* $5.00, 248 pp., 1954—Copper, silver, and gold are covered in this second volume of the series. Presented is a thorough coverage of chemistry of all significant compounds for these metals, processes for recovering the metals from their ores, and composition and properties of the alloys commercially available today.

Almost Sinusoidal Oscillations in Nonlinear Systems, Part III. Transient Phenomena, by J. S. Schaffner. *University of Illinois.* 40¢, 39 pp., 1953.—This is the third in a series of three bulletins dealing with a number of oscillatory problems. Phenomena discussed in this bulletin are parametric excitation, synchonization, simultaneous oscillations, and amplitude limitation by means of lamps.

Increased Production Reduced Costs Through a Better Understanding of the Machining Process and Control of Materials, Tools, and Machines, Vol. 3, by James Van Voast. *Curtiss-Wright Corp.* Wood Ridge, N. J., 153 pp., 1954.—The book begins with a refresher on the practical principles of metalcutting. It follows with a chapter offering an account of the refining and mining of the metal, its properties, and a discussion of the metallography. Other categories of titanium alloy handling are: Machining behavior; special techniques investigated; turning; milling; routing; drilling; tapping; abrasive cutting; hacksawing; belt grinding; surface grinding; and machining high-temperature jet engine alloys. For information on how to obtain the book, write to Curtiss-Wright Corp.



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Meet The Authors

P. J. Maddex (p. 734) is presently assistant plant manager with Titanium Metals Corp. of America, Henderson, Nev. Mr. Maddex was born in Ohio and received his chemical engineering degree (1941) from Ohio State University. He has been associated with General Electric Co., as an engineer; development engineer, National Lead Co.; and has been a research engineer at Battelle Memorial Institute, Columbus. He coauthored *Continuous Method Producing Titanium*, JOURNAL OF METALS, in 1950.

E. H. Rose (p. 740), a Member of the Southeast Local Section, AIME, has presented approximately 25 papers during his years of membership with the Institute. Born at Kinsley, Kan., Mr. Rose is a graduate of the University of Kansas. He began his career as a mill superintendent with the Patino Mines, in Bolivia. From 1928 to 1930 he held the same position with the Moctezuma Copper Co. in Mexico. For six years Mr. Rose was assistant mill superintendent for the International Nickel Co. of Canada. In 1936 he was promoted to mill superintendent, a position he held until 1945. He was named consulting metallurgist for the Copper Range Co. on the White Pine project in Michigan during 1946. He joined the U. S. Steel Corp., Tennessee Coal & Iron Div. in 1947 and until recently was a research engineer. He has been a member of the raw materials advisory committee, U. S. Atomic Energy Commission since 1949. He holds membership in several professional societies and has held numerous offices in the AIME. His hobby, as he puts it, is "trying to be a good member of AIME."

Robert F. Mehl (p. 728) has attended Franklin and Marshall (B.S.) and Princeton University (Ph.D.). He was also a national research fellow at Harvard University. Dr. Mehl began his career as a proctor fellow in chemistry at Princeton. He has been associated with Juniata College, Naval Research Laboratory, Armco Steel Corp., and Carnegie Institute of Technology. Dr. Mehl is presently head of the dept. of metallurgical engineering, director of the metals research laboratory, and dean of graduate studies at Carnegie. He has authored articles and books, and holds membership in professional societies, both in the U. S. and abroad.

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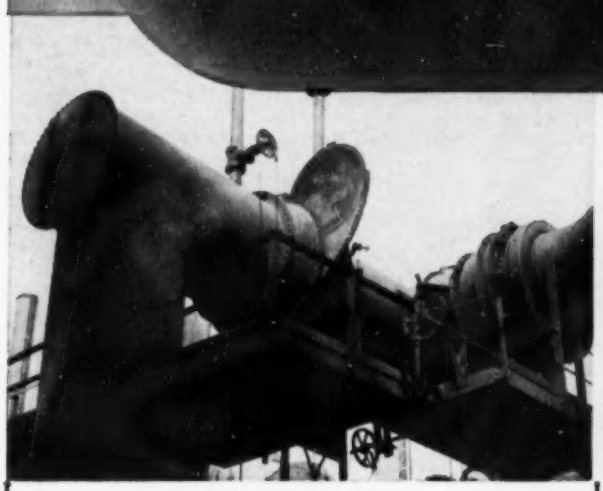

Mechanical Type

By means of a powerful clamping force applied equally at all points around the disc periphery, the Bailey Mechanical Goggle Valve provides a safe, tight seal for gas mains from 6" to 72" in diameter. The goggle plate is freed instantly by the same powerful mechanism, regardless of the length of time between operations. Both this type and Bailey Thermal Expansion Valves require only a minimum of maintenance.

Thermal Expansion Type

Designed for gas mains from 36" to 120", the Bailey Thermal Expansion type goggle valve operates by the linear expansion and contraction of three sets of steel tubes. When steam is applied, the tubes expand and separate the flanges, thereby freeing the goggle plate for swinging to open or closed position. When steam is removed, normal cooling contracts the tubes, which then clamp the flanges together to form a gas-tight leakproof seal. Can be hand-operated in case of steam failure.

WILLIAM M. Bailey COMPANY

ENGINEERS

1221 BANKSVILLE ROAD PITTSBURGH 16, PA.

Industrial Notes.

• Sintering of cemented carbide tools under vacuum conditions is standard procedure at Allegheny Ludlum Steel Corp.'s Carmet div., Detroit, since installation of an induction heated vacuum sintering furnace. F. J. Stokes Machine Co., Philadelphia, Pa., designed and engineered the furnace which supplements a battery of Stokes powder metal presses which form the *green* parts.

• **With the opening of the Rockdale plant of Aluminum Co. of America, Texas gained second place among states producing aluminum. The state has a capacity of 260,000 tons annually, or one sixth of the U. S. total. The four-potline plant at Rockdale has a capacity of 90,000 tons.**

• Representatives of the U. S. Air Force and the aluminum industry recently witnessed a demonstration of ultrasonic soldering of aluminum and ultrasonic treatment of molten aluminum by Aeroprojects Inc. It was shown how ultrasonics can be used to solder aluminum by production methods without using flux. At the demonstration ultrasonics also was used to remove gas pockets from molten aluminum and to refine grain structure of ingots.

• *A titanium analysis section has been established at Sam Tour & Co., Inc., 44 Trinity Place, New York City. The company lays claim to four years of titanium work under research and development contracts from the Ordnance Corps, U. S. Army.*

• *Armco Steel Corp. expects to start work soon on construction of a new clarifying system, expansion of mill scale collecting basins, new pumping stations and sedimentary beds, and much additional piping to handle recirculated water at its East Works, Middletown. The $1,250,000 project will help to conserve water resources of the Miami Valley, Armco stated, and will be coordinated with Middletown's new sewer and sewage treatment program.*

• **Sweden expects to jump iron output from 12 million to more than 17 million tons per year, with hopes that most of the increase will be exported, according to Erland Waldenstroem, managing director of the Graengesberg Co., the nation's top producer. Key to the increase will be the reorganization of two Lappland mines at Malmberget and Kiruna. They now produce about three quarters of Sweden's iron ore.**

• **The Naval Research Laboratory, Washington, D. C., is attempting to fill certain vacancies on its physical sciences and engineering staffs. Included in the list are: Electronic scientists with salary range of $4205 to $7040, depending upon research project; physicists, salary range from $4205 to $7040; and chemists, $5940. For the majority of vacancies no civil service status is required. Inquiries should be directed to W. G. Torpey, Code 1817, Naval Research Laboratory, Washington 25, D. C.**

• Annual Cornell Summer Laboratory Course in techniques and applications of the electron microscope will be given June 14 to 26 by the Laboratory of Electron Microscopy, dept. of engineering physics. The course is scheduled to be under the direction of Benjamin M. Siegel, with James Hillier, Melpar, Inc., and C. E. Hall, MIT, as guest lecturers.

• Another summer course on metallurgical applications of X-ray diffraction is to be given at MIT, August 2 to 13. The course will be under the direction of John T. Norton, professor of the physics of metals in the MIT dept. of metallurgy. For further data, write to Room 7-103, MIT, Cambridge 39, Mass.

For maximum efficiency in the production of specimens in the metallurgical laboratory the Buehler cabinet type polishing table with companion storage cabinets represents the latest modern development of this type of equipment.

The convenience of this streamlined polishing equipment saves time and encourages the operator to produce the highest quality of polished sample.

Item No. 1511 is a two-unit polishing table with Formica top approximately 60" long x 27" deep by 30" high to table top. Two 12" swing spouts, drain, 8" diameter wash bowl, plumbing and wiring.

Recommended accessories to complete an efficient set up for maximum convenience are: No. 1512 storage cabinet with recessed light and No. 1513 supporting panel for installation above polishing desk. Or, No. 1514 floor model storage cabinet. Both these cabinets can be used together to advantage in most laboratories.

The Formica top and back on the table and cabinet is installed with a smooth Formica edge that eliminates all metal rims that may form pockets for water and dirt. Covers are held in place on the back by magnetic holders. The large 8" wash bowl is a new feature that enables the operator to use both hands in washing specimens.

All metal construction finished in hammer tone grey makes a very attractive appearance. Prompt delivery can be made on these new items.

The Buehler Line of Specimen Preparation Equipment Includes . . . Cut-Off Machines Specimen Mount Presses • Power Grinders • Emery Paper Grinders • Hand Grinders • Belt Surfacers • Mechanical and Electro Polishers • Polishing Cloths • Polishing Abrasives

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NEW COST-SAVING PROCESS FOR FOUNDRIES

The Airco Carbide Injection Process in use at the American Brake Shoe Company, Mahwah, N. J.

Carbide injection method developed by AIRCO® cuts ductile iron alloy costs up to 50 percent

permits melting in acid cupolas

Many foundries that have limited their production to gray iron will soon enter the ductile iron field, thanks to a new Airco development. Desulfurization of molten iron by injecting calcium carbide can reduce sulfur content to such levels that ductile iron can be melted in ordinary acid cupolas. At the same time, this sulfur content — as low as 0.01 percent — makes it possible to cut the amount of expensive alloy elements drastically with no sacrifice of mechanical properties. Foundries already using Airco carbide injection report savings of up to 50 percent on these alloy costs alone!

The injection equipment itself is simple and inexpensive. It consists of a hopper and an injection tube through which the powdered carbide is injected into the molten iron by a stream of nitrogen. The operating expenses are the cost of the gas and the carbide, trivial in comparison to the savings they make possible.

Calcium carbide injection is a fruitful result of Airco Technical Service's constant effort to find new profitable techniques for customers. If you have a welding, cutting or metallurgical problem, why not let Airco help you develop the most practical approach to it? It can pay big dividends.

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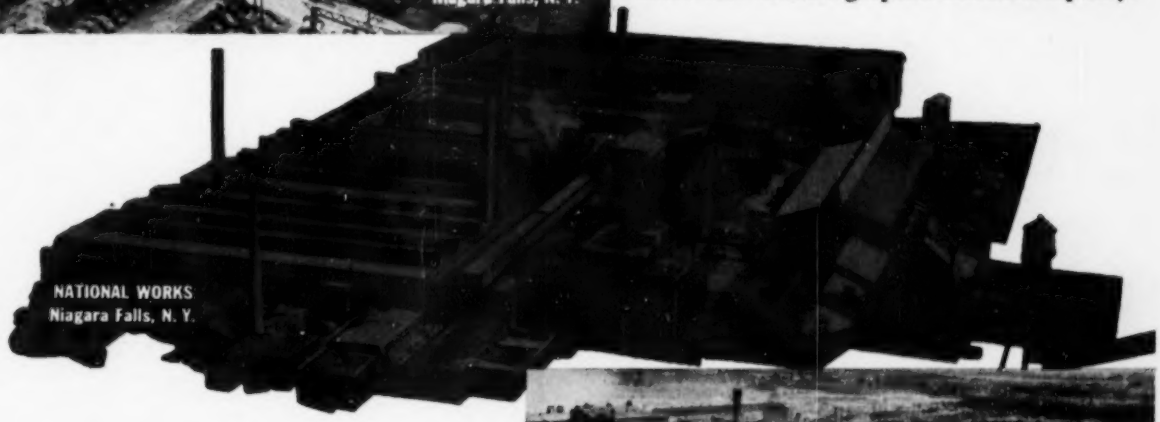
ELECTRODE QUALITY . . . has a direct bearing on the quality of *your* product; in many instances, it can materially affect your *cost*. National Carbon's graphite and carbon electrodes are, and always have been, the finest quality obtainable *anywhere*. We make this statement without reservation.

NEW PRODUCT DEVELOPMENT . . . is basic in technological progress. National Carbon has *always* done the major part of this country's electrode research and development . . . a share out of all proportion even to its outstanding leadership in the production and sale of these products. This is a matter of long-standing record.

PLANT CAPACITY . . . National Carbon's ability to *produce* is at an all-time high. The five plants shown here are fully integrated for production of both carbon *and* graphite electrode products — a situation rare in the industry and in keeping with National Carbon's far-sighted planning to pace requirements of a rapidly-expanding economy. For example, plant additions in the last five years alone have more than doubled graphite electrode capacity.



EXPERIENCE . . . of National Carbon is the foundation, building blocks and cornerstone of electrode-products manufacture in this country. First with commercial production of both carbon and graphite electrodes in the early 1900's, National Carbon introduced the first of each increasingly larger electrode size from that time to the present, plus a host of successful accessory items for improved application of electrodes in the metallurgical field. Today, National Carbon is the only company producing carbon electrodes up to 45" diameter; graphite electrodes to 35". Even larger electrodes and other massive shapes can be made with present facilities. Inquiries are invited.

RESPONSIBILITY . . . to customers and to the industry as a whole . . . expresses itself several ways in National Carbon history. The company has consistently kept ahead of demands for both quality and size of electrode products; National Carbon research stands virtually alone in the steady march of new product development; and, in the field of *service*, National Carbon is supreme. For many years we have conducted an expanding, electrode technical-service operation, staffed by a group of electrode experts, specially trained to help you get *more for your electrode dollar.*

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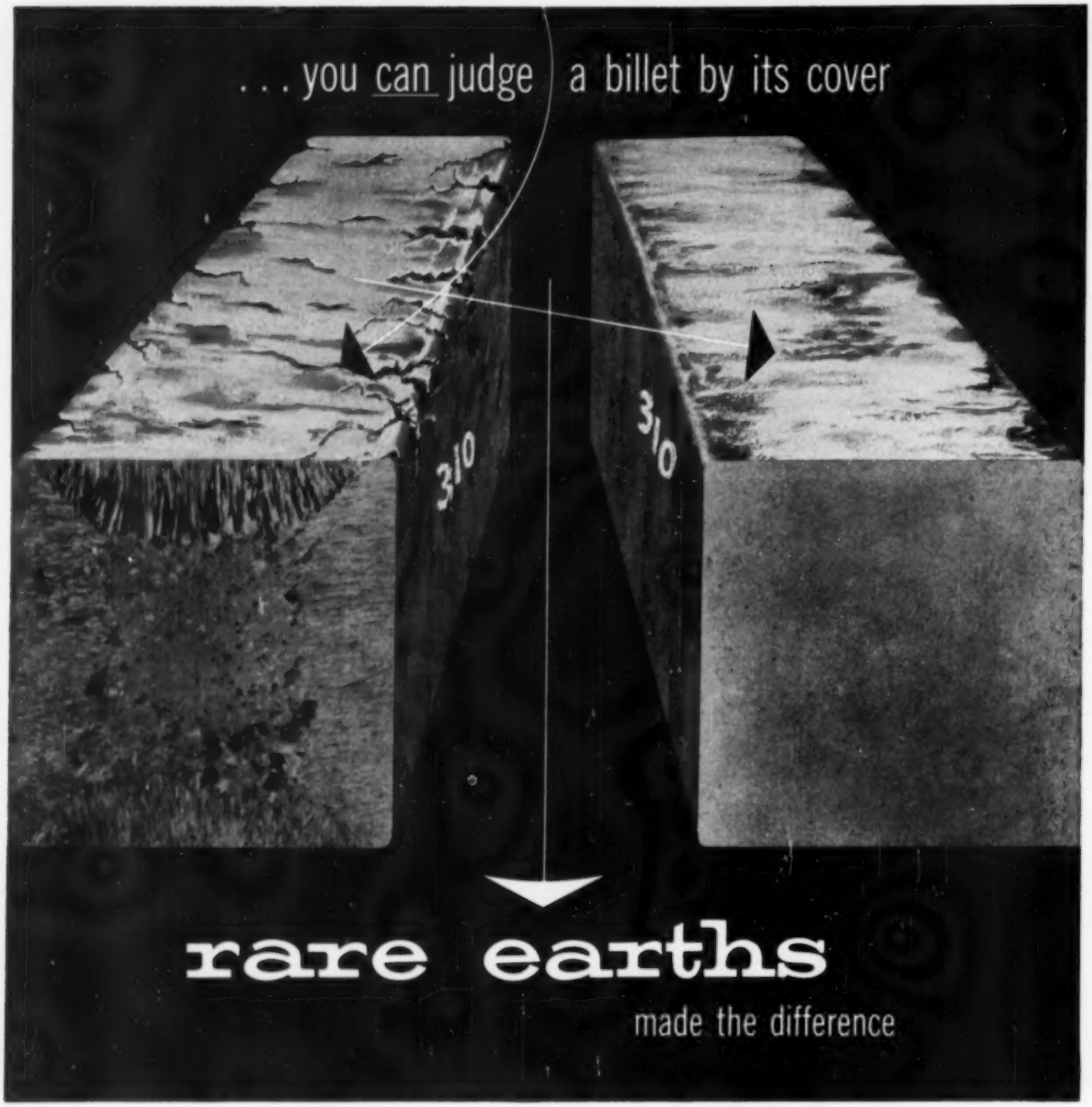

The two billets shown were produced by a prominent manufacturer of 310 stainless steel. Before rare earth additions, the billet on the left shows a coarse columnar structure, with frequent corner cracks. Heavy cogging was necessary to permit rolling with a minimum of hot tearing; after rolling a grinding loss from the edges incurred additional production time and expense.

Consider the billet on the right, and the great improvement made by a small economical addition of **MCA RareMeT Compound.** The fine primary crystal pattern shown in the sectional view is taken from an unretouched, unmagnified photograph. This steel was rolled without intermittent heating cycles from ingot to billet, and frequently to final size, all with a minimum of hot tearing.

MCA's RareMeT Compound is currently being used successfully in A.I.S.I. grades **309, 310, 316, 317,** and other stainless steel by many progressive producers. *Write today for further information.*

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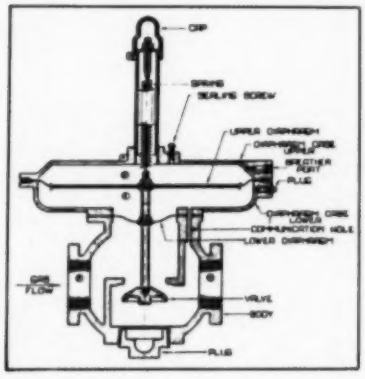
For Further Information or Literature on any Product, Fill in the Coupon and Send to JOURNAL OF METALS
Students are Requested to Apply Directly to Manufacturers for Bulletins and Information

1—TACONITE MOTOR: A motor for taconite mill service has been designed by *U. S. Electrical Motors, Inc.* Seals are provided with extra long sleeves of close tolerance and made of nonmagnetic material. They are composed of brass and bronze so that two dissimilar metals will be in an operating position to each other to present a completely nonmagnetic path. This special motor is also suitable for locations where the atmosphere is heavily charged with abrasive dusts such as cement mills, foundries, ore crushing, and in locations where dust and moisture are prevalent.

2—REGULATOR: Development of a ¾-in. low pressure demand type, air and gas regulator, capable of passing as much as 600 cu ft per hr 0.06 sp gr gas at 4 in. WC pressure drop, has been announced by *Paul-*

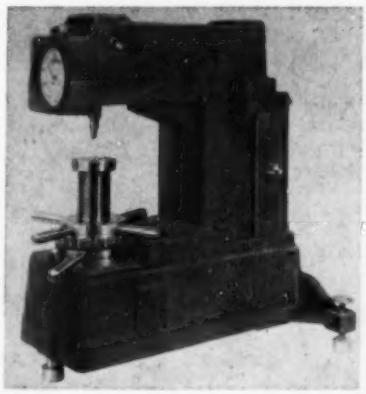


sen-Johnson Co. The new valve features accurate regulation to within 5/100-in. WC throughout its full range of operating pressures.

3—LIMIT SWITCH: A completely sealed heavy duty precision limit switch is announced by *Minneapolis-Honeywell Regulator Co.* The switch is designed for use on all types of machinery and industrial equipment where dust, dirt, abrasives, or liquids may be present.

4—CARBOTRONIK: Instrument designed and manufactured by *Ipsen Industries, Inc.*, provides an accurate and continuous method of automatically controlling the carbon potential of endothermic furnace atmospheres. Functioning electronically, the unit handles a wide variety of job requirements ranging from 0.20 to 1.25 pct carbon.

5—HARDNESS TEST: An instrument that can make regular and superficial Rockwell hardness tests has been developed by the *Torsion Balance Co.* It makes regular Rock-

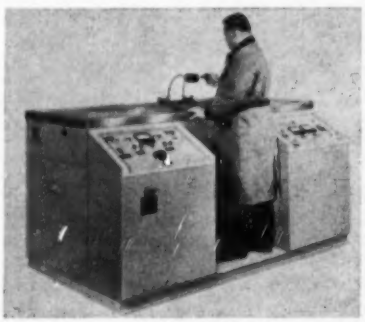


well tests (60, 100, and 150 kg loads) and superficial tests (15, 30, and 45 kg loads) with any suitable standard C, N, or Ball type indenter.

6—VAPORMASTER: A portable ultraviolet analyzer for measuring minute quantities of gas in air, with a full scale absorbance of 0.0025 on the most sensitive ranges is manufactured by *Manufacturers Engineering & Equipment Corp.*

7—TOOLHOLDER: A new combination of carbide tooling developed by *Vascoloy-Ramet Corp.* completely eliminates all carbide grinding. The combination consists of toolholders and throw-away carbide blanks.

8—INDUCTION HEATING: A combined high frequency generator and work table has been announced by *Electric Arc, Inc.* Rated outputs are



a full 10 or 20 kw and the units are rated for continuous duty.

9—SI RELEASE AGENTS: Two new silicon release agents are offered by *Dow Corning Corp.*, for shell molders who wish to use solvent type agents rather than water emulsions. F-496 and F-452 contain 5 and 50 pct solids, respectively, of high viscosity silicone fluids in mineral spirits. F-496 is designed for immediate use and F-452 is recommended for those who may wish to make up concentrations to meet their own specific operating requirements.

10—DIELECTROMETER: Design and production of a microwave di-

electrometer for measuring the dielectric constant and loss of a wide variety of materials has been announced by *Central Research Laboratories.* It operates at nominal frequencies of 1, 3, and 8.5 kilomegacycles corresponding to free space wavelengths of 30, 10, and 3.5 cm.

11—ANNEALING OVEN: To reduce heat strain in cathode ray tube button stems a new annealing oven has been developed that holds the stems in a vertical position during the heating process. This oven is of a conveyor type and has three heat zones, each of which can be controlled separately or as a unit, to provide the proper heat curve. *Steiner-Ives Co.*

12—AIR COMPRESSORS: Designed for spray painting and general utility work, this new line of portable air compressors is being introduced by *DeVilbiss Co.* The model designed for spray painting is a 1 hp model, rated at 600 lb max pressure and delivering 5.4 cfm of air. For general utility work a ½ and 1 hp compressor, having a 100 lb max pressure rating is available. The 1 hp unit delivers 4.2 cm of air and the ½ hp model has an output of 1.91 cfm.

Free Literature

20—IMPACT EXTRUSIONS: Significant facts necessary to design products as impact extrusions are covered in booklet issued by *Aluminum Co. of America.* Alcoa impacts are one piece, seamless, semihollow or solid parts having forged bases and one or more extruded side walls.

21—CHEMICALS: Brochure describing varied *Reynolds Metals Co.* aluminum chemicals is now available. Chemicals listed include: Alumina hydrates, activated aluminas, calcined aluminas, and bauxite, to mention a few.

22—SLING HOOK: Bulletin No. 90 gives complete facts and specifications on Tayco alloy sling hooks and Tayco grab hooks as well as other Taylor alloy steel hooks. Hooks are manufactured for ⅜, ½, ⅝, ¾, ⅞, 1, and 1⅛ in. chain sizes. *S. G. Taylor Chain Co.*

23—MASTIC COATING: Properties, uses, and application methods of Palladium mastic type T are reported in booklet available from *Palladium Mastic Corp. of America.* This is a rust proofing, corrosion resistant mastic coating for the exteriors of tanks, vats, ducts, and structural work of chemical process plants.

24—METALS FINISHING: Illustrated brochure describing the facilities of the *American Buffing & Polishing Co.* has been published. Included are photographs of the company's electronically controlled machines for custom finishing metal, plastic or rubber products of a wide variety of sizes and shapes.

25—MACHINING STAINLESS: *How to Machine Republic Enduro Stainless Steel Bars* is booklet obtainable from *Republic Steel Corp.* Speeds, feeds, and estimating data for machining all types of stainless used commonly on automatics are given.

26—CONVOLUTED COUPLINGS: Catalog No. 55 describing this new addition to the line of industrial expansion joints has been published by *Solar Aircraft Co.* These couplings were designed and engineered to meet industrial needs for low pressure and vacuum service joints. They are available in stock sizes from ½ to 72 in. pipe sizes.

27—TESTING MACHINES: Two universal testing machines of 20,000 and 60,000 lb capacity are described in bulletin announced by *Baldwin-Lima-Hamilton Corp.* Principles of hydraulic straining system and the Tate-Emery null method load indicator are given along with descriptions of accessories and specifications.

28—O RINGS: Booklet dealing with vented and standard O rings and various industrial applications for static sealing of high and low pressures and temperatures has been issued by *United Aircraft Products, Inc.*

29—FURNACES: Illustrated brochure on metallurgical furnaces is available from *Rust Furnace Co.* Furnaces for reheating slabs, blooms, and billets are included as well as design and construction of soaking pits, open hearth furnaces, heat treating furnaces for annealing, normalizing, patenting and stress relieving.

30—AIR CONTROLS: Advantages of using air control system on excavator cranes are described in brochure available from *Clark Equipment Co.* Case histories report actual operating experience with air controlled Michigan excavator cranes on construction, scrap handling, and steel erection.

31—DYNAMOMETER: Bulletin includes specifications on dynamometer models and also contains illustrations of new applications for this instrument. *W. C. Dillon & Co., Inc.*

32—CHEMICAL PROCESSING: The second edition of *Allegheny Metal in Chemical Processing* is available. Use of stainless steel in the manufacture of acids and other chemicals is covered. Corrosion resistance data, fabricating information, and a stainless steel finder are included. *Allegheny Ludlum Steel Corp.*

33—CRUCIBLE TONGS: Cradle type crucible tongs with new self adjusting contact pads are illustrated on bulletin sheet issued by *Industrial Equipment Co.*

34—FLAME SPECTRA: Pocket card showing flame spectra for typical inorganic elements is available from *Beckman Instruments, Inc.* Emission lines are superimposed on a full color spectrum from 300 to 900 millimicrons.

35—HEAT EXCHANGER: Bulletin No. 105 on *Thermal* type DF heat exchanger is available. The instrument is available for pressures of 300 psig and temperature of 1200°F, with high pressure and temperature designs available on special order.

36—BUTTERFLY VALVES: Specifications of butterfly valve bodies and the new series 800 diaphragm motor operators are described in bulletin 1701 issued by *Minneapolis-Honeywell Regulator Co.* Complete tables of allowable pressure differentials are included to facilitate selection of properly sized bodies and operators.

37—ELECTRIC OVENS: Brochure on electric ovens, gravity and recirculating, Magni-Whirl water baths, and lab-heat furnaces for general and analytical laboratories, pilot plant, and production is available from *Blue M Electric Co.* Units range in temperature from 100° to 2000°F.

38—HEAT RESISTANCE: Bulletin A-141 on heat resistant and corrosion resistant alloy castings in industry has been issued by *International Nickel Co., Inc.* More than 175 photographs illustrate applications of typical alloys. Tables of composition list designations as well as certain proprietary alloys.

Journal of Metals **June**
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Now, for the first time, electrolytic chromium metal is commercially available in tonnage quantities. It is being manufactured in ELECTROMET's new Marietta, Ohio plant. *Electrolytic chromium can be advantageously used whenever additions of chromium of low iron content are needed.*

For further information about electrolytic chromium metal and other ELECTROMET ferro-alloys and metals, please contact the nearest ELECTROMET office listed below.

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MEN have long sought to obtain power directly from the sun. The dream came closer to reality when Bell Telephone Laboratories disclosed that it had developed a solar battery that converts the sun's rays into electricity. The battery is simple looking, and is composed of 2½x½ in. silicon wafers imbedded in a transparent plate. But its history can be traced back to at least the first decade of the 20th century.

The battery has an efficiency of 6 pct, according to Bell, and compares favorably with steam and gasoline engines. Other photoelectric devices have never been rated higher than 1 pct. Improved techniques are expected to increase efficiency. Right now, the battery can operate a walkie-talkie, transmit voices over telephone wires, and run a transistor radio carrying music. With no moving parts and nothing to wear out, indefinite life expectancy for the battery is envisioned.

The solar battery is still in the experimental stage, but it may get practical application soon. A rural telephone line is under trial at Americus, Ga. using Bell-invented transistors. It is hoped that the line will prove possible greatly increased rural service without additional wires. The solar battery could be used, according to Bell, at amplifier stations along the line. Solar batteries may also be employed as power supply for mobile, low-power equipment.

Developed by three men—G. L. Pearson, C. S. Fuller, and D. M. Chapin—the solar battery depends on a new technique for the controlled introduction of a foreign element into a microscopic layer near the surface of the thin slice of silicon, as illustrated in Fig. 1. C. S. Fuller developed the process which consists of simply heating the semiconductor wafer in the presence of a suitable impurity vapor. This provides essentially a p-n junction, which, when built into germanium single crystal is the basis for the junction transistor. (William Shockley covered p-n junctions in JOURNAL OF METALS, August 1952). According to Bell, the impurities reach a depth of less than one ten thousandth inch.

While some envision rooftops covered with silicon strips supplying enough power to light homes, Bell scientists are loath to make predictions. The experimental battery solar strips linked together deliver power at the rate of 50 watts per sq yd of surface. It would take about 100 sq ft of silicon wafer surface to keep a 100-watt lamp burning all day.

Photoelectric devices can be traced back to the early part of the 1900's, when semiconducting crystals provided one of several competing wireless detectors. The vacuum tube won out. In 1930 Bell's R. S. Ohl demonstrated that the erratic crystal detector could be made reliable and reasonably efficient. Ohl interested J. H. Scaff in finding a way to remove impurities from the silicon to which the metal point of the detector was applied. Impurities were segregated by careful freezing of a silicon melt, starting at the top. A large part of the ingot was found to be satisfactory for use in microwave detectors. Ohl discovered that the process produced in such ingots the first known p-n junctions. Imperfect and inefficient, they were still the prototypes of all photoelectric devices. Scaff and H. C. Theurer identified the p-type impurity as boron and the n-type as phosphorus. They went on to make the first p-n junction by adding these impurities to molten silicon and diffusing them in the solid state. Other impurities with similar qualities have been unearthed since.

Following World War II, William Shockley and his Bell Laboratories group attacked the many problems connected with the physics of semiconductors posed by this work on silicon. During the course of this work, John Bardeen and W. H. Brattain discovered the point-contact transistor, in germanium rather than silicon, because the former was more easily rendered pure. Shockley formulated the complete theory of p-n junctions and junction tran-

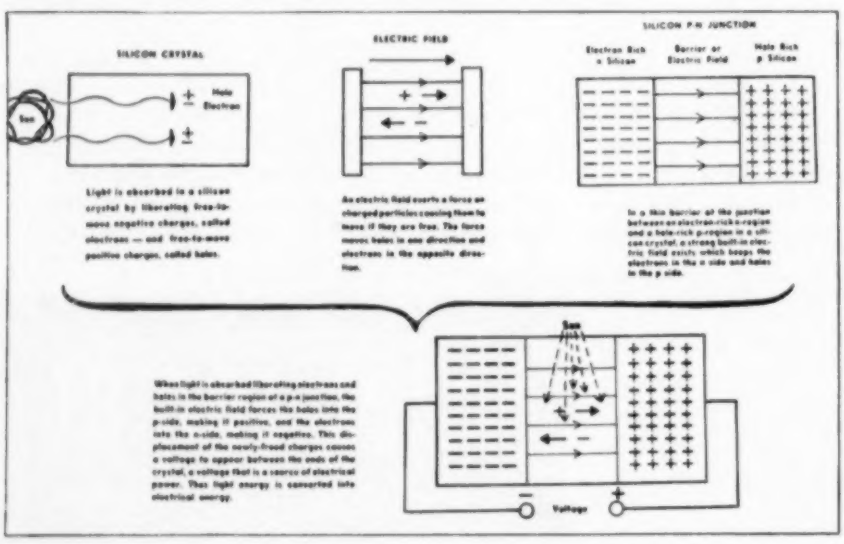

Fig. 1—This is how the Bell solar battery works. Thus far, only small quantities of electricity have been produced, enough to run small units. However, more significant performances are expected as the battery is improved.

sistors. At this stage Bardeen and G. L. Pearson developed a systematic understanding of the physics of both n-type and p-type silicon, providing an important part of the foundation for silicon devices. Experiments had shown that pure silicon single crystals were better than germanium for certain functions. Silicon was better for computors and switching elements, for solar energy conversion, and for various transistor actions at higher temperatures.

In the first step toward application of this knowledge, G. K. Teal and Ernest Buehler grew silicon single crystals. Careful fractionation, including distillation of silicon derivatives, in the second step toward use of silicon, led to unequaled purity in the element.

J. R. Haynes and J. A. Hornbeck supplied additional information on the electrical processes of semiconductors. The building of p-n junctions into the silicon crystal has been done in several ways. Pearson first made p-n junction rectifiers by welding aluminum wires to silicon. Baldwin Sawyer and D. K. Wilson went on to develop a finished device. Recently, N. B. Hannay and Buehler employed special crystal growing techniques for construction of silicon transistors.

In making the large area solar batteries, D. M. Chapin developed the technique pioneered by Fuller and Pearson. These diffusion techniques, Bell states, show great promise of wide application to many kinds of semiconductor devices made from both germanium and silicon.

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C. G. SUITS, vice-president and director of research, General Electric Co., in disclosing the development of perfect crystals of iron, felt that for the first time a metal had been developed that was as strong as it should theoretically be. Such crystals "provide a new and exciting dimension in metallurgy." Mr. Suits described the crystals as metallic whiskers about one-thousandth of an inch thick and an inch or so in length.

The crystals were produced at GE's research laboratory in Schenectady, N. Y., by Robert L. Fullman and Arno Gatti. Mr. Suits noted that "No one knows how to put these perfect crystals to practical use. We certainly cannot use them to support a suspension bridge. But their discovery is very recent. In time, applied science and technology will find a practical use for this form of metal."

The whiskers were tested at the laboratory by bending. Strength was calculated from the maximum elastic strain sustained before plastic deformation. Plastic deformation occurs by the formation of a sharp kink when the maximum strain exceeds about 2½ pct. GE has not released details of how the iron whisker crystals were grown.

First observations of metallic whiskers were made at the Bell Telephone Laboratories where telephone relays under test were found to fail mysteriously. Research showed that whiskers of tin had grown and caused a short circuit.

Mr. Suits reviewed the fact that iron crystals which had been calculated in the laboratory to be strong enough to support 1 million psi, were found to have one hundred times less strength under actual conditions. The reason remained a mystery until it was discovered that crystals previously made and thought nearly perfect actually had irregularities on the atomic scale, resulting in the weakness.

He reports strength of the new iron crystals is astounding. "They are stronger than any previously known metal or alloy, and actually attain a tensile strength of nearly 1 million psi." The iron crystals appear to be rust resistant because "The same atomic perfection that gives them strength prevents oxidation."

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AN additional 100,000 persons have been added to the iron and steel payroll since the end of World War II. Employment during January 1946 averaged about 575,000 persons. In 1953 steelworkers, not including ore and coal miners, numbered some 683,000. In addition to more jobs, more hours per week have been worked by wage earners in the industry.

A survey last year showed that the average steelworker has two dependents. Simple arithmetic indicates that 300,000 more persons derive their daily bread from the steel industry than in 1946. They outnumber the population of Omaha, which had a population of about 250,000 according to a 1950 census.

Six increases in the wage scale in the eight years ending December 1953 amounted to 81.3 pct of the average hourly payroll cost. Accompanying wage increases have been such additional benefits as hospitalization, pensions, and group insurance.

The end of 1953 saw a definite reduction in total employment in the steel industry. Yet, some 656,000 remained on the payrolls, for a net gain of 81,000 over the 1946 average.

The increase in steel industry employment can of course be traced to the 35 pct expansion in capacity which cost some $5.6 billion since the end of World War II. With the general expansion came improvements not only in production facilities but working conditions and safety. Better lighting and ventilation, smoke control, operating pulpits giving more protection from heat and fumes, and modernization of materials handling equipment were among the things which accompanied expansion.

During the first quarter of 1954, ingots and steel for castings were being produced at a rate of about 90 million tons per year. Steel capacity, as reported Jan. 1, 1954, is 124.3 million tons. If steel production continues for the remainder of the year at the rate set in the first quarter, it would mean less than 1200 lb per capita. Capacity per capita is at a new high of 1500 lb for each person in the U. S.

Drift of Things

IT would be hard to convince the Secretary of the Metals Branch that there is a better time to spend three weeks in the southwestern part of the United States than early May. To reach the majority of the Extractive Metallurgy Div. members the Division Secretary must travel west. We were sorry to miss the excellent Pacific Northwest Regional Meeting and the equally fine New England Regional Meeting this year but had much new territory to cover. The first stop was Denver where we spent several hours with Colorado Section officers C. L. Barker and R. L. Scott. This section is undergoing extensive changes to serve AIME members better.

It was only a short plane ride the following day to Pueblo and the Colorado Fuel & Iron Corp. Here we had an opportunity to meet J. J. Martin, vice president of operations, Rudy Smith, works manager, and many of their staff including Bill Carpenter, Past-chairman of the Southwestern Section of the Open Hearth Committee. John W. Monson, Vice Chairman of the Pikes Peak Sub-section, arranged both a plant trip and an evening sub-section meeting. C. H. Carlton, Chairman, and H. R. Keil, Secretary-Treasurer, traveled a considerable distance to attend this meeting.

Thursday evening found us in El Paso where O. Paul Lance, Chairman of the Section, arranged for a get-together with a dozen of the most active members of the section. The following day Bernard B. Kunkle took us through the Phelps Dodge refinery, Dean Thomas of Texas Western College arranged for a meeting of the student chapter, and Ben D. Roberts showed us the AS&R smelter. We left El Paso in time to drive to Carlsbad to have dinner with Howard P. Clark, Chairman of that section. The following morning we met Charles L. Jones and D. J. Bourne, section officers, and visited the International Minerals & Chemical Co. and the Duval Sulphur & Potash Co. The underground mining of potash and the froth flotation separation of large crystals of potassium chloride from sodium chloride were indeed intriguing. Saturday afternoon we did not pass up the opportunity of seeing the Carlsbad Caverns.

Monday morning we were in the area of Silver City, N. Mex., where we visited the Kennecott properties. W. H. Goodrich, general manager, is Chairman of the Local Section and arranged for a section meeting that evening. David W. Boise, Secretary-Treasurer of the section and then Mayor of Silver City (no trouble cashing a check here) drove us around to see many of the mines in the area which, because of the price of lead and zinc or the fact that the mines had been worked out, were no longer operating. The next stop was Morenci, Ariz. and Lester D. Olson, Chairman of this sub-section, had arranged for a meeting that evening. We had an extensive visit with L. M. Barker, Chairman and L. L. McDaniel, Secretary of the Arizona Section, a very effectively organized section with both geographical and technical interest subsections. Their extensive program owes its success to the hard work of the committee members and the fine support given by the companies.

So far we had traveled mostly by plane but an air conditioned Greyhound now brought us to Inspiration where P. D. I. Honeyman, vice-president and general manager of the Inspiration Consolidated Copper Co., made arrangements for a visit. The ore is leached and the copper recovered from solutions electrolytically. A few miles away, Harold Foard, International Smelter Co. superintendent, took us inside the reverberatory being rebuilt after tapping it ten feet below the normal tap hole! Needless to say that tap produced a tremendous amount of matte. We hope the paper already given at the Arizona smelter section meeting explaining this unusual bottom erosion may be presented at the Annual Meeting.

Magma Copper Co. was the next stop and W. P. Goss, Past-chairman of the Arizona Section, had arranged for a visit. The 150°F mine wall temperature is compensated for by high grade copper ore. It was nice to have lunch here with Walter Schmid, treasurer of both the company and of the New York Local Section. We finished in time to hear the last paper at the Arizona Open Pit All-day Meeting at Ray and to meet, among many others, Robert Hughes, general manager of the Miami Copper Co., Abe P. Morris, general manager of the Kennecott Copper Corp. at Ray, Ariz., J. C. Van de Water, Chairman of the Open Pit Group and Ernest R. Dickie, general manager of the Bagdad Copper Corp., all of whose operations it would have been nice to have visited had time permitted.

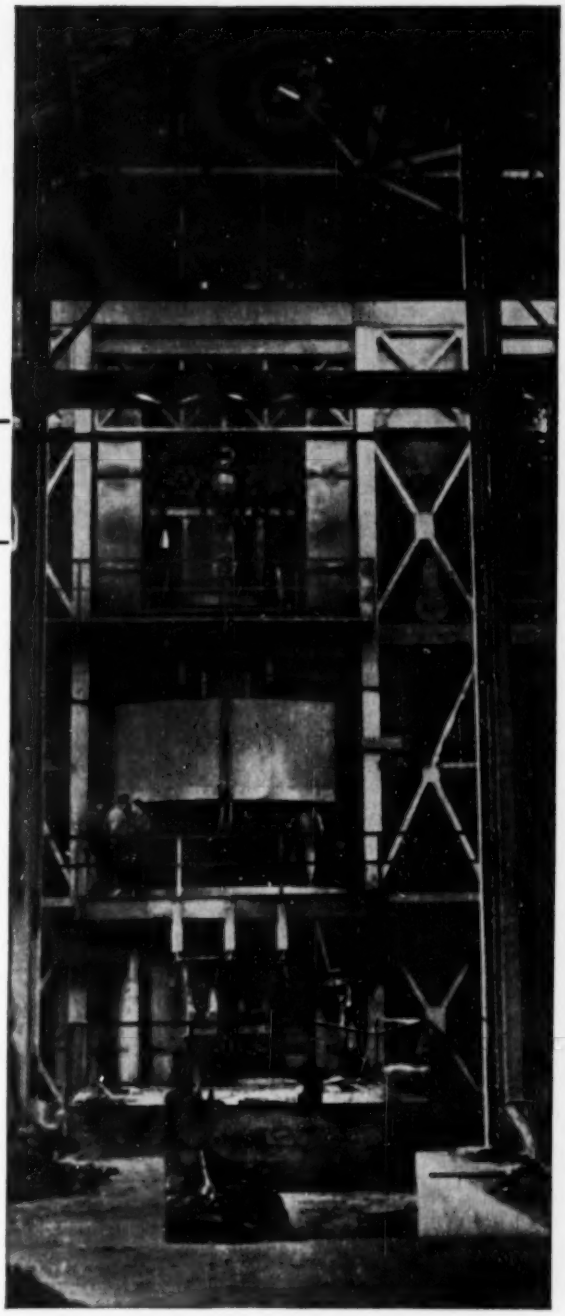
In commenting on the ideal weather suffice it to say that the plane scheduled to land at Flagstaff, Ariz. for a weekend visit to the Grand Canyon landed at Winslow because of the amount of snow on the runways. Sunday evening, Theodore Page, Chairman of the Ajo Sub-section, met the plane in Ajo where it was 80°F. W. T. Sullivan, Vice-chairman, had arranged for a luncheon meeting of the sub-section. A. T. Barr, general manager, J. W. Byrkit, smelter superintendent and J. A. Lentz, mine superintendent and their staffs saw that we had a fine plant trip. At the University of Arizona at Tucson, Professors Cunningham and Krumlauf arranged for a student chapter meeting under the chairmanship of Charles Leonard and a tour of the campus. The last stop in Arizona was the Douglas-Bisbee Sub-section. James E. Foard is Chairman and after a complete tour of the plant he had arranged for a dinner meeting of the sub-section officers. In Bisbee we met Carl E. Mills, manager of the Copper Queen Branch of Phelps Dodge and members of his staff while visiting a new concentration plant ready to go into operation.

The last stop was the Cananea Consolidated Copper Co. just below the border. C. P. Donohoe, vice-president and assistant manager, was a most gracious host. Robert C. Weed took us through all of the operations including an extensive trip underground. For one who has crossed the border to Canada many times a crossing into Mexico is a contrast.

Ernest Kirkendall

*Lectromelt**

goes to Chile to produce ferroalloys . . .



One of the eleven Lectromelt Furnaces in Chile. This Lectromelt Smelting Furnace produces ferroalloys at its Chilean installation.

In 35 countries around the world, Lectromelt Furnaces are at work. This international acceptance results from the special care given to the design of each Lectromelt. Plenty of metal goes into the sturdy parts assembled into each unit. Clamps, supporting arms and operating mechanisms are built generously for long life and little maintenance.

For example, to support heavy smelting furnace electrodes, Lectromelt uses as standard equipment a special multi-shoe, readily adjusted, remote-controlled clamp for continuous self-baking electrodes.

It's taken years of experience to obtain world-wide confidence in Lectromelt Furnaces. Take advantage of this furnace know-how when you start thinking about a new electric.

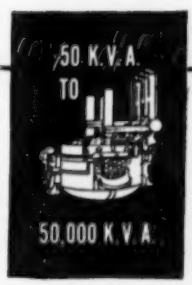
Write for Lectromelt's new Catalog 105 which describes furnaces for smelting and refining operations. Pittsburgh Lectromelt Furnace Corporation, 326 32nd Street, Pittsburgh 30, Pennsylvania.

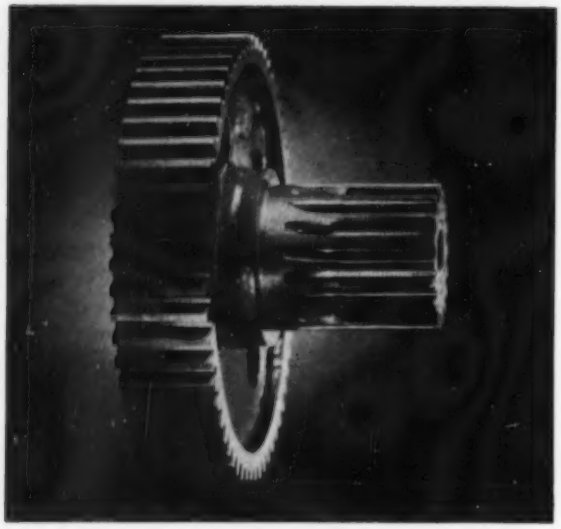
Manufactured in . . . ENGLAND: Birlec, Ltd., Birmingham . . . FRANCE: Stein et Roubaix, Paris . . . BELGIUM: S. A. Belge Stein et Roubaix, Bressoux-Liege . . . SPAIN: General Electrica Espanola, Bilbao . . . ITALY: Forni Stein, Genoa. JAPAN: Daido Steel Co., Ltd., Nagoya

*REG. T. M. U. S. PAT. OFF.

MOORE RAPID

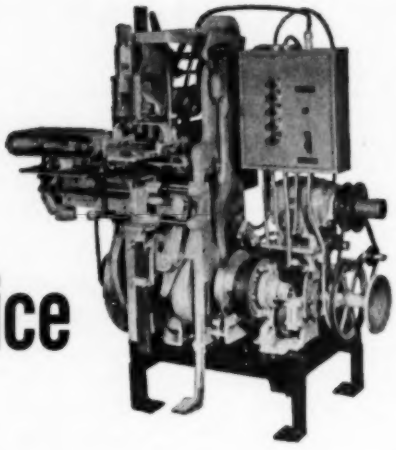
WHEN YOU MELT... *Lectromelt*





Fit as a fiddle . . . aptly describes this Ductile Iron camshaft drive gear. It was installed in an automatic labeling machine on March 3, 1952, at Bestway Products, Inc., Rahway, N.J. Ductile Iron "as cast" provides high strength, resistance to wear and galling, with good notched endurance properties. Inspection of the gear on June 15, 1953, found it to be as good as new and it's still on the job.

12 TIMES Longer Service with Gears of Ductile Iron



Harmony in motion . . . is essential in the musical record business, where downtime of equipment stops deliveries with dire results. Look at this "Pony Label-Dri" automatic labeling machine, produced by New Jersey Machine Corporation, Hoboken, N.J. One of this type labels records for Bestway Products, often 'round the clock.

"You can't sell Christmas records in January."

That's the way Louis Quitoni, Plant Superintendent, of Bestway Products, Inc., put the problem when his labeling machine – geared for 1,000,000 records a month – kept breaking down.

Imagine the backlog that built up, and what happened to deliveries . . .

Until this Ductile Iron gear was installed.

"The latest gear . . . machined from a Ductile Iron casting," writes Bestway Products, "has given a truly remarkable performance."

* * *

The two principal requirements of this gear are 1) a high order of wear resistance and 2) ability to withstand sudden shock loads imposed by a knife clutch. This machine is intermittently operated and tripped 3 or 4 times a minute.

So far, Ductile Iron has given 12 times the service of high test iron gears which failed in about 2 *months*. So far, the initial Ductile Iron replacement has served 2 *years*, and it's still on the job.

New Jersey Machine Corporation, builder of this machine, as a result of this service life has standardized on Ductile Iron for camshaft drive gears for original and replacement installation.

In plants from coast to coast, Ductile Iron is saving money at every turn. How? By its remarkable load-carrying ability and wear resistance, combined with excellent castability, ready machinability and moderate cost.

Send us details of prospective uses. We'll gladly suggest a source of supply from some 100 authorized foundries now producing Ductile Iron under patent licenses. Request a list of available publications on Ductile Iron . . . mail the coupon now.

The International Nickel Company, Inc.
67 Wall Street, New York 5, N. Y.

Please send me a list of publications on DUCTILE IRON.

Name_____

Title_____

Company_____

Address_____

City_____ State_____

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N.Y.

Republic Steel Corp. hired Robert P. Peterson, nuclear physicist, to study and develop use of nuclear materials in steel production. Dr. Peterson is chief of the Industrial and Production Reactor Development of AEC. Republic also reports it has acquired what may prove to be the largest rutile deposit in the Western Hemisphere. The deposit is located in southern Mexico.

Defense Mobilizer Arthur Flemming announced that the Government will buy up to 4000 tons of surplus titanium sponge and hold it for eventual resale to manufacturers of aircraft and other equipment. About 40 pct of the slightly more than 5000 tons of titanium sponge to be produced in 1954 will be surplus.

Titanium Metals Corp. of America is using titanium as a skin covering for helicopter rotor blades. Formerly, steel was used for the rotors. Weight saving through use of titanium is said to be 68 lb.

Part of the U. S. loan of $100 million to the European Coal-Steel Community is earmarked for the mining industry. Jean Monnet, chairman of the High Authority told the community's assembly that the extractive industries are to get $25 million for new equipment and modernization. He pointed out that the community had made it possible for European nations to obtain favorable financing, new credits, and more productive use of resources "which no one of them could have obtained alone."

Peru hopes its steel plant now under construction at Chimbote will be producing coke and some pig iron by next year. It may be several years, however, before steel is actually produced. Marcona Mining Co., owned jointly by Utah Construction Co. and the Harvey Mudd interests of Los Angeles, is committed to supply Chimbote with up to 300,000 tons of ore per year at 28 pct of world market price.

Jones & Laughlin Steel Corp. has taken an option on iron ore bearing land owned by Gulf Oil Corp. six miles from Kirkland Lake in northern Ontario. J&L emphasized that proposed exploration activity will not result in immediate large scale development.

The Brazilian Trade Bureau in New York City reports that Brazilian steel expert General Ibere de Matos discussed plans for establishing a joint public and privately owned corporation to build a 900,000 ton annual steel capacity plant at Vitorio, Brazil. Another mill with 450,000 tons annual capacity is planned for the state of Santa Catarina.

Carnegie Institute of Technology

The Nature of Education In Metallurgical Engineering

by Robert F. Mehl

THE title of this paper is given as *The Nature of Education in Metallurgical Engineering.* The paper is indeed largely that, but I have included much that is auxiliary to the main subject, feeling that such augmentation might be of interest to those who care about the subject. It is a sort of brief essay on metallurgical education; it does not treat anything in detail, but instead attempts to arrive at value-judgments that must motivate the educator.

Education is a rather subtle thing, with even aims and objectives not lightly to be decided, and the good educator, the really able professor, does not often enjoy the luxury of certainty, of finality. There are a few basic principles that he will fight for, and these will be enumerated, but there are many that are fringe in certainty, especially as to teaching methods, that, like a problem in research, need constant reconsideration.

At the outset perhaps we should say just what we mean by metallurgical engineering. We mean, at least I shall mean, that composite of learning and of abilities-to-do that is generally recognized, primarily in the industry, as of consequence to those who call themselves metallurgists or metallurgical engineers; but we shall mean more than this, at least so far as a definition of use in devising training is concerned: we shall mean also those matters, scientific and engineering, which the leaders of industry confidently believe will be of importance to the industry in the near future. Extrapolation is necessary, leadership must be exercised. If twenty years ago some metallurgical engineers did not believe that good science was important, they misapprehended the future; the true leaders, recognizable on other grounds, did so believe. So it must always be; engineering is not history, dealing only with what has already transpired, including this day; it anticipates and thus progresses.

Metallurgical engineering is not that which chemists, or physicists or other types of engineers do with metals, though it may include in its broad bosom much of this. A metallurgical engineer is not a chemist, though he must know basic chemistry; he is not a physicist, though basic physics is a foundation stone to him. Metallurgical engineering is, like many another discipline, a thing-in-itself, with a unique body of material and of method, and certainly of ultimate general aim.

R. F. MEHL is Head, Dept. of Metallurgical Engineering; Director, Metals Research Laboratory; and Dean of Graduate Studies, Carnegie Institute of Technology, Pittsburgh. This paper was presented at the AIME Annual Meeting, New York, Feb. 15 to 18, 1954.

Aims in Education

There are tempests in colleges these days, as everywhere. This is especially true in liberal arts colleges and universities. Aims are not sure; Dean Hacker of Columbia University in the newspaper recently accused such institutions of wasting the students' time and of wasting college resources in a gargantuan way, in activities but vaguely related to the primary purpose of creating intellectual maturity. I think there is much real basis for worry in this. But this is not a worry for engineering schools; students in engineering schools work; there are few, if any, trivia about; proper work leads to pleasing mental maturity, at least so far as the limited subjects pursued are concerned.

The problems that professors in metallurgical engineering face are not these, but different ones. Some problems cannot be solved by educators in metallurgical engineering alone: there is but little we can do concerning pre-college education; there is not much we can do to attain the ideals of the broad-gage university in general education, though with care we can and have developed a consistent scheme of learning in social-humanistic subjects. Our problem is to devise metallurgical curricula, in the full sense of the word; the problem is somewhat less embracing, it is simpler.

Engineering colleges themselves are not quite sure on certain points. I have much sympathy for the problems of the engineering colleges, perhaps naturally. Such colleges are caught between inadequate high school training, and an ever-expanding goal. What can we do about high school training? Probably nothing, or at most very little as engineering professors. Every serious-minded educator will say that training in high schools for college, especially for engineering colleges, is in many places inferior to what it was a generation ago. Day-to-day experience confirms this; high ranking students graduate from high schools without having written a single theme. This is not bias, rooted in nostalgia—entrance records show fewer preparatory courses in mathematics and modern foreign languages, indeed the latter have become almost non-existent.

This narrow basis of criticism is damning enough; how much more could we say about methods, particularly the extremes of progressive education in which the young are guinea pigs without any discernible intellectual future. Many, many high schools, beridden by highly uncertain theories of social advancement, disclaim any responsibility in pre-college training. A superintendent of public instruction some years ago told me so bluntly in an open meeting. Colleges have to admit freshmen with inadequate preparation, and there is little or nothing that they can do about it. Only the citizen, on a local level, can work the dreadfully needed change, and it will take a long time.

And on the other end, the sciences and the branches of engineering have advanced so much in the last generation that one hardly knows how to fix an educational scheme. In part, I think, this comes from ambition: we wish to think of each of the branches of engineering as a true profession,—and largely deceive ourselves. How can a truly professional man be created in four years in college, when dentistry, law, and medicine require much more. We aspire to too much. There can be such a thing as a four-year bachelorate in science, but not, I think, in engineering. I should be happier, on so many counts, to have it five, with a more rationally arranged curriculum and with a nearer approach to the aims and ideals of general education. Some schools have this, and one day all will, and it should be soon.

Pressed from the beginning and from the end, we must do our best, and we need to say what this is.

Stress Basic Principles

It is not at all possible to train a student in such a way that he can accept full responsibility as an engineer in industry on graduation. We can hope only to train for internship. We cannot train in all of the current technologies, in welding, in foundry, in heat treatment, in cold rolling—the list is entirely too long even to enumerate. There is a most serious fallacy in any scheme that would provide this training: technologies are largely ephemeral; how we weld today will most surely not be how we will weld tomorrow. It should be added, as eloquently as possible, that this does not mean ignoring engineering.

The only feasible scheme, and, more than this, the best conceivable scheme, is to pick a series of basic principles both in science and in engineering, that will, in metallurgical engineering with the broad field it encompasses, be large in number, and then to devise an educational scheme around these, using current technologies as examples. There are many ways to do this; perhaps one example will be enough: the principles of heat flow, having both scientific and engineering aspects, can be taught as such, and engineering examples are numerous, offering many chances for calculation and problem solving,—the *sine qua non* of education.

The student may be confronted with an example of a design of a zinc condenser, which is intended to condense so much zinc in a given time period, and asked to demonstrate quantitatively whether air dissipation is enough or whether forced cooling is required,—and thus learns about zinc condensers; or he may be asked to calculate the half time of cooling of a piece of a given steel in a given quenching medium, and thus learns about quenching, with a happy engineering cross-reference to T-T-T curves. Time is too short to prove the efficacy of this scheme, but it works very well indeed.

The basic principles must be learned, principles that will apply as well to a process yet to be invented perhaps by that very student who makes the calculation as well as to current or ancient practice. (In technology ancient may be only last year!) To know current technologies in a descriptive way is barren education; to know principles and to know how to apply them in an analytical way is germina-

The Metallurgical Education session at which this lecture was presented was arranged by the Education Committee, Institute of Metals, AIME. This session under the chairmanship of John Chipman was a part of the Mineral Industry Education Div. meeting held at the Columbia University Faculty Club, Sunday evening, Feb. 14, 1954.

The lecture is printed as given by Dr. Mehl. In an aside during his talk, Dr. Mehl remarked that he could not hope to do justice, in the time allotted, to a subject which would require volumes for full treatment, and said later that for printing it was a little oratorical. It is the opinion of the editors, however, that he not only does justice to his subject but also provides a firm and challenging basis for further discussion.

tive education, leading, through ingenuity, to new processes, new materials. This makes sense, nothing else does. Whatever is learned must be learned completely, with full understanding, and encyclopedic knowledge must be sacrificed to this end. As Herbert Spencer said, "When a man's knowledge is not in order, the more of it he has, the greater will be his confusion."

Thinking and Doing

All this is a discussion of methodology, though of principle too. Implicit in it is a broad principle which should now be made explicit. It is not the aim of engineering education to provide knowledge; it is the aim to provide a series of what we might call, tersely, abilities-to-do. This is in fact embodied in the familiar phrase, that has become so meaningless, to make a student think; but we need to define a little better.

The world, and even a branch of engineering, can use pure scholars, persons who only know and can rarely, if ever, do. But neither has very much use for them. Certainly an engineer is characteristically an individual who acts: he builds a bridge, designs a process, runs a factory, creates an alloy—a complex special form of designing in itself. In a given engineering discipline a faculty has to decide just what abilities-to-do are required in a graduate engineer—remembering he can be but an intern on graduation. This is not difficult, though the task is certainly time-consuming, requiring much thought and debate; industrial advisors are very useful indeed in this connection.

With this decided—Carnegie has long had a formulated analysis on this—then one can reason about ways and means to accomplish the end. Analysis and problem solving are basic to this educational rationale. One does not attempt, or should not, in science as well as engineering, to produce mere *Gelehrte*, mere scholars; avoiding this extreme, it must be said at once—in order not to fall into the trap of the over-professional pedagogue—that useful balance must be sought and attained, no one learns to do an engineering task without basic knowledge. These two must be hand-in-hand, reciprocally and in reciprocation.

It can probably be seen that all of this ignores the questions of options, to such a degree that you may suspect that I do not like the thought—I don't! Should one, either in a formal option or in substantially equivalent elective courses, become enamoured? Surely he has fallen in love with a chimera. Few students can project their careers so surely as to predict the type of industry in which they will work; options represent specialization and provide little mental capital for the kind of progressive innovation that broader metallurgical training will supply. Industries are increasingly adopting this point of view,—training should be fundamental and broad in this sense.

Nor do I believe in another deviation, training in the science of metals, not in metallurgical engineering. There have been some successes in this; but the product, predisposed by education in this direction, runs a serious risk of limited horizons in opportunity and in accomplishment in industry, the life of the laboratory drudge is too hard to escape; only if a man should go on to graduate work can this be really useful. But graduate work can be done superbly by those who have the type of training here advocated, and such men in graduate work, knowing engineering, bear a special advantage even in fundamental research. Progress in the science of metals has so often come from those, granted with good fundamental training, who have been able to tap the magnificent source of metallurgical phenomena that is on display in industry.

In its extreme form, training only in the science of metals perverts into training in the physics of metals. There is a disease abroad in this, to which metallurgists, especially graduate students, show a wholly ill-advised, unnecessary vulnerability. I doubt that so many words have been written with so little result, that integral signs have ever been more profligately expended, that so little experimental verification has ever been attempted, as in the pursuit of the elusive dislocation.

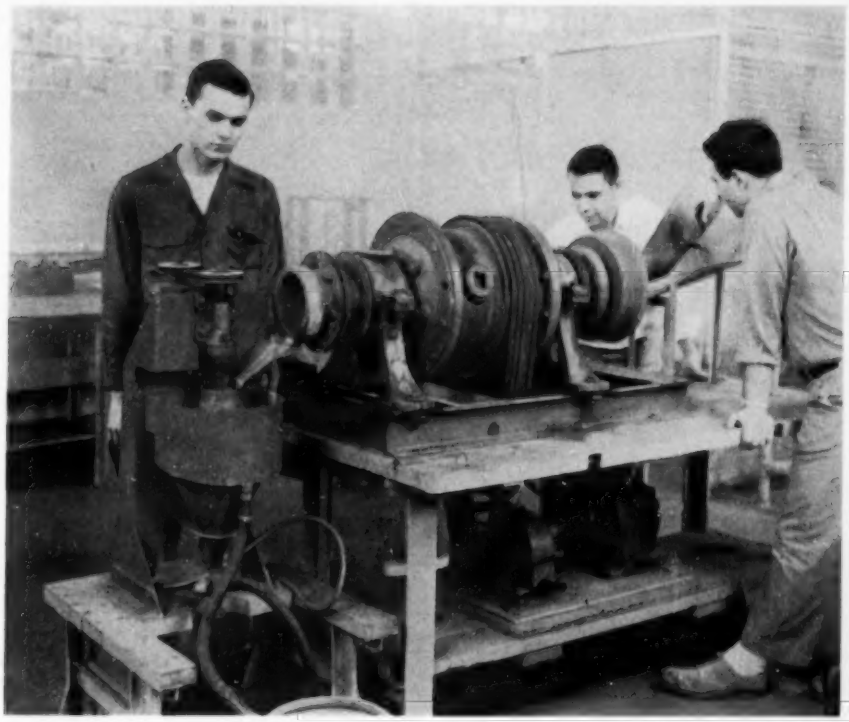
There is a snobbery in this, a looking down the nose, that which the physicist maintains toward the chemist, forgetting that he in turn is looked at askance by the mathematician, and he in turn by the philosopher, all a pretty silly business. Of what good is it to turn a good metallurgist into a cheap physicist in an excess of preciousness; the metallurgist has his own field and it is he who has largely built the science of metals; this is of course not to say that those who properly profess the physics of metals have not contributed, but only to say that divers people contribute. As Sauveur remarked, pithily, some twenty years ago, "What is new in all this; we have always benefited by those in any science who have studied metals; in 1896 we had a joint meeting on this,—then it was LeChatelier and Ewing; each generation it will be someone, but it is not a new movement.". Let the metallurgical schools turn out good metallurgists.

Metallurgical Curriculum

With the field thus circumscribed and aims and objectives selected, one may turn to the devising of a curriculum. It will not be the purpose of this brief essay to describe courses, laboratory experiments—all the in-fighting that goes with detailed educational planning. No one pattern of course is sacrosanct, the same goal may be reached with different curricular patterns. We ought, however, to state a few operating principles.

A student in his freshman and sophomore years prepares himself, largely, in basic sciences. Frequently an introductory course is given in the sophomore year, but his real metallurgical education begins in his junior year and continues into his senior year. There is much basic metallurgical science to learn, in physical metallurgy we usually call it the science of metals; in extractive metallurgy it is the special forms of physical chemistry metallurgists need. Logic and practice dictate that the basic science of the first years evolve into basic metallurgical science (largely created by metallurgists themselves) in the intermediate years, with an introduction to engineering, and then evolve into true engineering courses in the last portion of the curriculum.

Finally there should be a synthesis in one or more courses where all courses, including the social-humanistic, merge into the ultimate. Perhaps that ultimate goal should be stated in terms of what it is that an engineer should be able to do and toward which education is directed: he must be able to recognize an engineering problem, he must be able to identify and apply the pertinent principles of science, he must devise practicable engineering solu-



Junior students in the process metallurgy laboratory study the basic principles in the operation of a ball mill.

tions, employing to the full all of the principles of engineering he knows and will continue to learn, he must use the ingenuity in the art of engineering with which nature has endowed him and education and experience have matured. And he must then subject whatever solution has occurred to him to the economic analysis that will determine whether society can afford it,—and finally he must consider whether society, as an aggregate of humans, will accept it. This composite is indeed engineering.

Science and engineering have labored through many a revolutionary era; it is unfortunate that the word science has ordinarily meant the sum of universal knowledge, with the overtone that it is, as was once disastrously thought of Aristotelian science, full and finished. If 80 pct of what I know now about metals was not known when I was a student, how then can we bring a student to anticipate the same experience?

Development of Skills

If basic learning and problem solving is the primary mode of education, two aspects of this need then to be stated: it is of first importance that no student gathers an impression that that which he learns in school is the totality of knowledge, he must learn that on-the-job he will, in connection with any assignment, always be faced with further study, with resultant further personal development. It is not difficult to inculcate this attitude in the student.

Beyond this, the second point, he must learn about research, so that he may clearly understand that science and engineering are plus ultra, unfinished, with new important things to come in the future, and so that he may understand enough about research to be able to work with research men with understanding, even if he is not one of them himself. The pedagogical conclusion from this is that teaching should provide opportunities, in class and especially in the laboratory, to make the point. Laboratory work is the great opportunity; experiments should not be stereotyped; while designed to illustrate general principles, at least a substantial portion of them should be designed to let the student find out things for himself, even to the extent, occasionally, of wholly undirected experiments, where a suggestion is made to the student to observe a given process and to decide what observations to make and to make them. We find that this can, with moderation, start even as early as the freshman year.

Supplementing this, though at considerable educational expense, senior theses, research in nature, have proved to be extremely valuable with us. Respect for the difficulties of research is created, and even a modest result, especially when publishable, is wonderful educational adrenalin.

No simple statement can be made about metallurgical education more confidently than that the problem itself is not simple, no readily written curriculum suffices; surrounding simple aims and objectives there are essential supporting efforts that provide the needed polish on separate facets of a many-faceted object. Apart from learning in metallurgy itself, there are other essentials—wholly apart from purely curricular matters, such as learning in social-humanistic subjects.

Writing is vastly important; it cannot be expected that courses in English will suffice; the importance of the matter must be preached (preachment has its place despite the professional educators' insistence that one learns *only* by doing); and writing must underlie all course effort, with the professor serving always as a mentor in the matter of composition. Devices are available: Seminars in both junior and senior years discipline students; but every written

thing, in any and every course, which the professor sees, is another chance, never to be lost. With inadequate training in high schools, engineering schools do rather well in this—but it must be said that no training can assure really fine writing; this is a rare quality, like excellent speaking, not often to be found no matter what. And these same words can be transposed to apply to public speaking, for which well designed seminars are essential.

Beyond these, academic organizations should provide some opportunity to help the student to transcend the school, to begin to adapt to a future; I have no thought here of what is ordinarily meant by training for life and love; as ordinarily meant this is not the task of the university, else dilution will provide very watery education,—such matters are for the family, the church, the community. I mean an opportunity to grasp a long range view of metallurgy in the industry, as much a part of education as learning the phase rule.

The professor himself, knowing industry, can do much, but any device that will put practicing engineers in touch with students is good; we have accomplished this in a number of ways: we have a brief course which we call *Modern Metallurgical Practice* that brings prominent metallurgists, young and old, to the campus, and, allied to this, we provide for the visiting of plants by students. This latter plan needs a bit of elaboration: simple visiting is a fearful waste of time; such visits need educational planning, and need to be associated with course work—we do this, industrialists are very pleasantly cooperative, and the faculty recognizes the importance of the scheme.

There are other correlative activities that ought to be fostered; student metal clubs offer many advantages, especially in a proper development of faculty:student relationships, and in once again offering students opportunities for initiative and enterprise. Such clubs lead to good and useful alumni groups that can minister in many ways to institutional good. I would be the first to warn that some of these matters must not be allowed to grow and absorb, for they are clearly secondary, but they are none-the-less of recognizable importance.

Industry and University Relationship

"No one," wrote Thomas Arnold, "ought to meddle with the universities, who does not know them well and love them well." No doubt this is axiomatic; and it may well serve to introduce that old subject of the relationship between faculties in engineering schools and metallurgical engineers in industry, between the engineering school and industry.

I recently read some notes on this subject I wrote twenty years ago. They were plaintive. No doubt I was too young, but no doubt also my colleagues in the industry were unhelpful and a little unsympathetic. Happily things are now different. Once truly fundamental science and engineering was derided; now, especially since younger, better-trained men are coming into prominence in management, there is no basic difference in opinion. Now all agree that training in the engineering school must be nearly exclusively fundamental.

The town-and-gown situation has not been really critical for generations. No aspect of this must be allowed; mutual respect on both sides must be had. The good professor of metallurgical engineering must respect and if competent will not be able to avoid respecting what his industrial associates think of education. He must use them as advisors—though *only* as advisors. The full responsibility is his,—and it should be, for he is a specialist in his subject of teaching; he has studied it for years. He knows what can and cannot be done, and as well what should and should not.

He has his own profession. He must resist any pressure to teach a host of specialized and descriptive courses, chiefly on principle and also because of utter impracticability. If he does badly, the fault is his; if he does well the credit is his. Acknowledging this, let us say immediately that no one man is an absolute authority, that even the metallurgical teaching profession must not assume an attitude of *ex cathedra*.

The professor is dealing with a subtle and difficult thing, education, and needs to change his ideas as he recognizes a greater right, from the opinions of his colleagues and from the opinions of the metallurgists in industry. Curricula and the whole gamut of the educational effort should be submitted to industrialists; if institutional ideas are good, they can be easily explained and justified; if bad, such talk will make that clear; if questionable, discussion can only be good. Industrial advisory groups, provided they are properly selected, are good; both parties benefit. Association with industry should be close.

The financial plight of the college is serious and more dangerous than the casual spectator appreciates. The question is simply money; as Durant says in the recent book on the Renaissance, all civilizations have been built on money, and the college in many ways is the embodiment of civilization. The college and the college professor have outlived kings, political systems,—even dire poverty and the cartoonist; they will always be with us, but they will not necessarily be able to fulfill their important functions as they should. I can testify on the difficulties of attracting able young men into the teaching profession; here I think industries could help. Moreover, salaries in the higher academic ranks offer little long-range encouragement to the young.

There must be ways found that will keep men of real ability on college faculties. Raiding of faculties must stop, else the product of the college will become poorer. Good young men must be constantly added to college faculties—they must not be drained off with superior salaries, superior research facilities. Industry itself could solve this problem. The whole subject should be made the subject of a serious-minded conference between educators and industrialists. And in research, it is disturbing how little basic research is supported in colleges by industry; the government has assumed the burden—perhaps it should, for there are arguments for this, but it means, in one way or another, control by the state. Perhaps these matters are digressive from the main theme, but they weigh heavily in the minds of educators.

Graduate Education

In a paper such as this, graduate work should not be ignored, but there is hardly time to say very much on this large subject. As things stand today, graduate work in metallurgy in this country is largely scientific in nature rather than engineering in type. As such, I am inclined to think it is in very good shape; the educational problems are lesser than in undergraduate education; though the effort is relatively new, it has profited by the examples of

Members of the Carnegie Institute of Technology research staff plate a radioactive isotope on a metal.

other disciplines, it has not had to hew its own way. I think that curriculum is not a problem; the basic sciences of metal behavior that graduate students should learn are rather self-evident; the rapidity with which they are now advancing, witness the journals these days, gives the professor an arduous job of selection and organization, but presents no problem of intent.

Standards of student performance must be very high; and above all else, it must be seen to that the graduate student works independently to the greatest possible degree,—one should be especially emphatic on this point with respect to doctoral research. To make a graduate student effectively a research assistant to the professor is the worst sort of a perversion. Thesis subjects should be reasonably difficult ones, upon which the student himself bears the major part of the responsibility for experimental accomplishment and theoretical thinking. The professor must be a coach, with only a few signals from the bench, intruding himself preferably only when the player is getting hurt.

It was said a moment ago that graduate work is largely in the scientific aspects of metallurgy; the demand for such men far exceeds the supply, and ways should be found to ameliorate this critical shortage; in the long view, engineering colleges should develop graduate training that is more nearly engineering in type, as other branches of engineering have, for there is a large market for such men, but this will require more graduate students, and increased funds. I think that educators have been somewhat remiss in this.

Faculty Qualifications

It would be enjoyable to write an essay on what constitutes a good university professor. I am a little afraid that a really definitive essay might result in mass resignations at Carnegie; and if such an essay included an analysis of what a head of a department should be, this head might fall! But I ought to say something on this, for while tomes have been written on pedagogy, they would be and are of very little use if a faculty is not a truly distinguished one,—everything hangs on the quality of the faculty, nothing compares to this in importance.

Colleges cannot afford many specialists-in-the-ivory-tower; indeed I should be inclined to say that any is an unnecessary luxury, at least in engineering faculties. Even in the serious duty of advancing basic knowledge, with education an essential duty of the college, it is over-precious to think that ignorance of industrial practice is of no moment; as said earlier, too many of our finest efforts in basic research have come from men, like our chairman, who have partaken in the whole of the metallurgical gamut. Too few of modern scientific idealists realize that Willard Gibbs designed gears; that Einstein contributed to engineering, that Langmuir made so many of his contributions by studying the electric light bulb.

The college professor must be a devotee; there is no opportunity for the money-grabber, or even the extreme careerist. In the ideal case—for which one strives—he should be both a good teacher, with all that implies, and at the same time a good researcher. Such people do exist, and young men can even be trained to reach this goal. Yet no mold fits them all, nor should the professor be all things to all men.

What can be done is to see to it that within a metallurgical faculty, somewhere, each and every quality needed is represented; this can be organizationally planned. The professor should be given a remarkable degree of freedom within only moderate organizational confines. That which passes from professor to student is intensely personal and subtle, and is a precious thing, with the good of the youth of the land, and even the good of the land, at stake.

Fig. 1—Titanium Metals Corp. of America is a fully integrated company located at Henderson, Nev. Production operations start with ore and include the melting of sponge to ingots.

Titanium Metal Production Expanded at Henderson Plant

by P. J. Maddex

TITANIUM METALS CORP. OF AMERICA produces titanium by reducing titanium tetrachloride with metallic magnesium. The plant is located at Henderson, Nev., about 15 miles from Las Vegas and Hoover Dam. The plant, shown in Fig. 1, occupies a part of the original Basic Magnesium facilities erected during the war to produce magnesium by the Magnesium Elektron process.

This process differs from the Dow in that concentrated chlorine is produced as a byproduct from the cells. The Basic Magnesium process involved chlorination of magnesia to produce the magnesium chloride used as the cell feed. Briquettes of calcined magnesite, carbon, and a binder were fed to form a bed in large shaft furnaces, and chlorine was passed upward through the bed. Molten magnesium chloride was tapped out of the bottom of the furnaces and off gases consisting principally of CO, CO_2, and HCl were treated in a series of condensing towers.

The similarity of this equipment to that required for chlorination of TiO_2 containing briquettes to produce titanium tetrachloride, is apparent. Acquisition of these facilities, therefore, provided the following: A—Equipment adaptable to the production of titanium tetrachloride, B—a captive magnesium plant to recover magnesium and chlorine from the byproduct magnesium chloride, C—power from Hoover and Davis Dams, and D—a supplementary supply of chlorine available from an adjoining plant of Stauffer Chemical Co.

P. J. MADDEX is Assistant Plant Manager, Titanium Metals Corp. of America, Henderson, Nev. This paper was presented at the AIME Annual Meeting, New York, Feb. 15 to 18, 1954.

Plant Operations

The basic flow sheet shown in Fig. 2 is relatively simple. Rutile is chlorinated in the presence of carbon at high temperature to form titanium tetrachloride. This compound is carefully purified and then reacted in large retorts with molten magnesium metal. The titanium sponge formed is separated from the excess metallic magnesium and the magnesium-chloride reaction product and then melted in arc furnaces to produce large ingots of titanium or titanium alloys.

Original facilities were for the production of one ton of titanium metal per day. This was increased to four tons per day with additional and, in some cases, modified equipment as well as processing steps. At the present time capacity is being further expanded to produce 10 tons per day.

The rutile used as plant feed is about 95 pct TiO_2. Rutile was chosen as a feed material because of the economic and engineering problems involved in separating iron chlorides produced in the chlorination of ilmenite. Ilmenite is far the more plentiful domestic ore of titanium but contains only about 40 to 60 pct TiO_2.

The TiO_2 content of the two ores alone point up some of the many problems associated with using domestic ilmenites as a feed material for TiCl, pro-

duction. These technical and economic problems must of necessity be solved since a healthy and large titanium metal industry has to base itself on domestic ilmenite rather than imported rutile.

Rutile is blended with ground coke using coal tar as a binder. The blend is thoroughly mixed and fed onto the bed of a circular tunnel kiln where the volatiles are burned off and the tar is coked. A loss of carbon content occurs during firing; therefore, the mix is formulated so that the fired material retains sufficient carbon content to react with the oxide in the TiO_2 during chlorination. The ratios of raw materials employed have been determined on the basis of experience. At the tunnel kiln discharge the mixture is a coked, porous, hard mass which is broken into fragments to form briquettes.

Fig. 3 is a diagram of the chlorination furnace which is maintained at a temperature 800°C or higher partially by means of power supplied through carbon resistor blocks in the bottom and partially by the heat of reaction generated during the chlorination. Briquettes are fed intermittently into the top of the chlorinator to form a bed on top of the resistor blocks, and chlorine gas is passed upward through this bed of briquettes.

The gaseous TiCl is evolved together with CO, CO_2 and some excess chlorine. Theoretically when using pure TiO_2 and carbon, all the briquette constituents should be converted to volatile products. In practice, however, the impurities in the rutile (silica for instance) plus fragments and powdery unreacted briquettes form a residue or ash which continually builds up in the furnace so that eventually it must be shut down and cleaned. Efficiency of operation of the chlorination furnace depends largely on the quality of briquettes employed and on the care with which charging and general operation is accomplished.

The product gases from the chlorinators pass through dust collectors to remove suspended solids and then into the $TiCl_4$ condensors. These are vertical towers into which cold liquid titanium tetrachloride is sprayed. Condensed $TiCl_4$ is pumped to

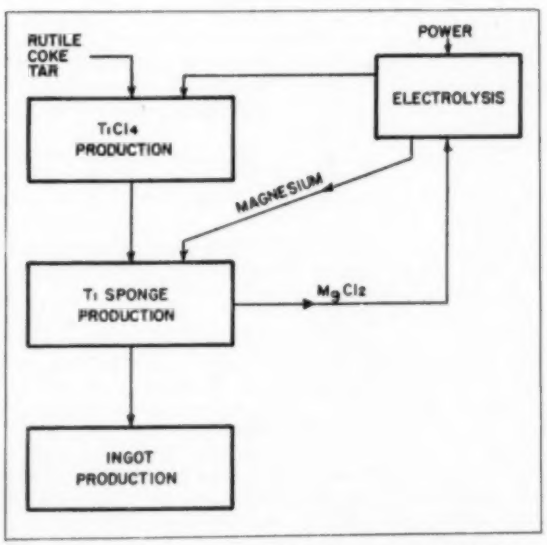


Fig. 2—Flow sheet of operations gives essential steps in producing titanium. One of the steps is the reduction of $TiCl_4$ with metallic magnesium.

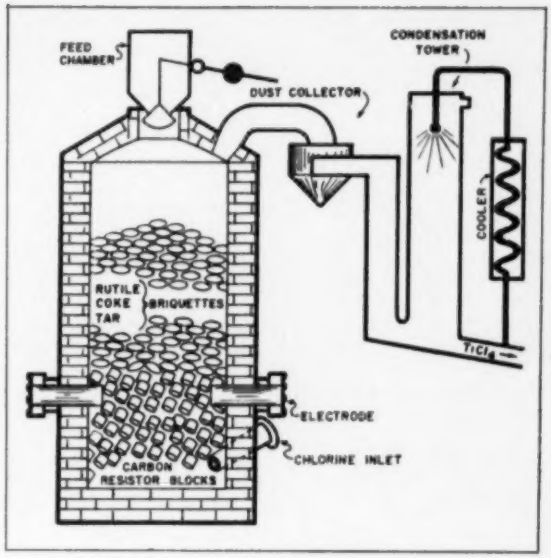


Fig. 3—Diagram of the chlorination furnace illustrates the method of producing $TiCl_4$. The furnace is maintained at a temperature of 800°C or higher.

a settling tank where insoluble matter and sludge are separated. It is then ready for purification.

The development of processes for the production of titanium metal have depended on using a starting compound that could be freed from oxygen and nitrogen. $TiCl_4$ has properties that make it amenable to purification by distillation. Most of the impurities can be removed by fractionation. Compounds, such as $VOCl_3$, which have boiling points near that of $TiCl_4$, can be altered by chemical treatment thus changing their boiling points. Using these principles $TiCl_4$ of high purity is produced.

Reduction of Chloride

The basic principles involved in the reduction of $TiCl_4$ by metallic magnesium have been described in papers published by the U. S. Bureau of Mines.[1, 2] The reduction process as practiced by TMCA is carried out either by reduction and vacuum distillation in the same vessel or by reduction followed by a leaching treatment.

For the first process, the retorts comprise an outer shell and an inner reaction pot fitted with a simple plug valve operable from outside the structure. The retorts are carefully cleaned before each reduction and then charged with metallic magnesium. After assembly and leak checking the temperature is raised to about 850°C, and titanium tetrachloride is fed in onto the molten magnesium. Meanwhile the interior of the retort is maintained under positive pressure of helium. Sufficient magnesium is employed to provide an excess over the tetrachloride used and these reactants are calculated to produce a sponge batch of about 500 lb. During the addition of the tetrachloride, titanium metal and the magnesium chloride are formed. In order to keep residual magnesium available for reaction and to insure best usage of reaction pot volume, magnesium chloride is intermittently drained from the reaction pot into a chamber in the bottom of the retort.

When all the $TiCl_4$ has been fed into the reactor and the cycle is complete the titanium sponge prod-

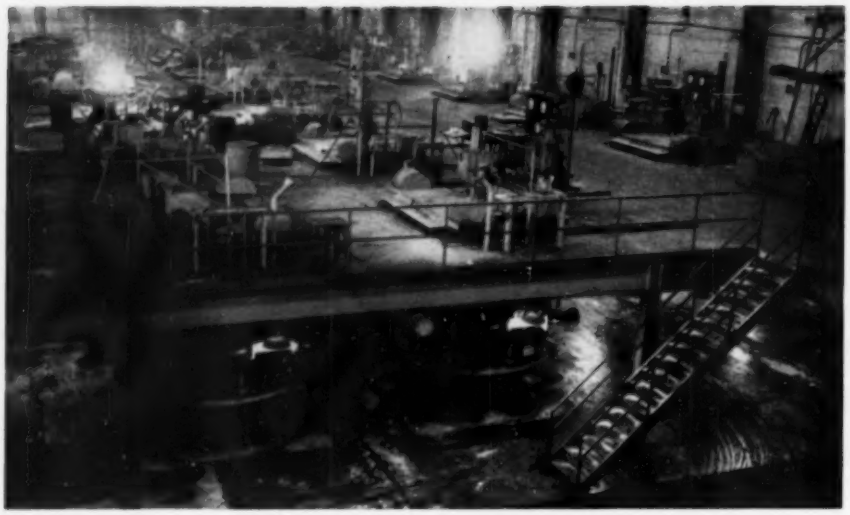


Fig. 4—Reduction of $TiCl_4$ is carried out in reactors where the titanium sponge is separated from excess metallic magnesium and magnesium chloride by vacuum distillation.

uct is separated from the excess metallic magnesium and magnesium chloride by vacuum distillation. The reactor is retained in the furnace, vacuum applied, and the heat maintained at 800° to 900°C. Under these conditions the magnesium and magnesium chloride are vaporized from the sponge and condensed in a portion of the reaction vessel which is maintained cool. After distillation the reaction vessel is removed from the furnace and placed in a cooling station. When the temperature has been reduced sufficiently so that the reactor may be opened without oxidation of the product, the titanium sponge is removed and crushed. The interior of the reduction building is shown in Fig. 4.

A part of the Henderson sponge production is freed from magnesium and magnesium chloride by leaching. A slightly different type of reactor producing approximately 1500 lb of sponge is employed for this phase of the operations. The reaction vessel does not have to resist the effects of the high vacuum employed when distillation is used. The reduction cycle is carried out in essentially the same manner as that previously described.

After the reaction is complete, the reactor is immediately cooled. The titanium and magnesium chloride byproduct are removed from the pot in a horizontal boring mill. A special large diameter cutter is employed and the operation is adjusted to produce chips of a size not exceeding about 1-in. in largest dimension. All boring operations are carried out in a room maintained with a dry atmosphere to prevent moisture pickup by residual magnesium chloride in reaction vessel.

The chips are fed slowly into a tank containing a special acid solution which dissolves the magnesium and magnesium chloride and does not affect the titanium metal appreciably. It is necessary to avoid high temperatures in the leaching tanks as the solution reactions produce considerable exothermic heat. Therefore, the chips are fed slowly into the acid over a period of time. After leaching the chips are washed thoroughly with water and then dried. The drying temperature is carefully maintained to provide adequate drying without oxidation of the titanium sponge particles.

Magnesium chloride byproduct drained from the reactors is used as feed for cells as installed in the original plant. Electrolysis of this high purity magnesium chloride supplies recycled magnesium for reduction and chlorine for manufacture of $TiCl_4$.

Arc Melting Furnaces

Consolidation of the titanium chips into ingots is accomplished in arc furnaces. Batches of chips, selected by analysis for the particular purpose intended, are carefully blended and compacted into briquettes. Each briquette, if required, contains alloying elements. The melting furnaces are of special design and contain a water cooled copper crucible into which the electrode is melted. Original ingots are about 17-in. diam and weigh about 1800 lb. A portion of the production is of 24-in. diam double-melted ingots almost two tons in weight.

After melting the ingots are turned to remove surface imperfections and finished ingots are shipped to Allegheny Ludlum mills for conversion to bar, open die forgings, wire, and flat rolled products.

Commercial production of titanium metal involves very careful handling of all process steps. The propensity for titanium to absorb oxygen and nitrogen and become embrittled and comparatively useless is well known. This fact is responsible for many if not most of the processing difficulties encountered in the industry.

The present process for reducing titanium oxides to a quite pure metallic state is undergoing constant change leading to better uniformity and greater quantities at lower cost. While generally acknowledged as not being the ultimate production method, the current procedure is yet the only means of getting reasonably large quantities of this critical metal into military equipment.

TMCA is carrying on a full program of research and development work on all phases of titanium metal and alloy production.

References

[1] M. A. Cook and F. S. Wartman: Removal of Magnesium and Magnesium Chloride from Titanium Sponge by Vacuum Distillation. Report of Investigations No. 4837 (February 1952) U. S. Bureau of Mines.

[2] H. C. Fuller, D. H. Baker, Jr., and F. S. Wartman: Recent Practices at the Bureau of Mines, Boulder City, Nev., Titanium Plant. Report of Investigations No. 4879 (May 1952) U. S. Bureau of Mines.

Air view shows the plant at Babbitt, Minn. Main plant is already under construction on Lake Superior shore.

Taconite Beneficiation Comes of Age At Reserve's Babbitt Plant

by Oscar Lee

RESERVE Mining Co., owned jointly by Armco Steel Corp. and Republic Steel Corp., controls 9½ miles of magnetic taconite ore on the eastern end of the Mesabi Range lying between Mesaba and Birch Lake. The ore reserve which can be mined by open pit methods is conservatively estimated at 1.5 billion tons under a shallow, loose overburden requiring no rock stripping.

Taconite now being mined is in the upper cherty horizon. It has been metamorphosed by the intrusion of gabbro and most of the iron oxide is altered to magnetite. The nonmagnetic portion of the iron is practically all in the form of silicate. The magnetic iron is finely disseminated through the rock and requires grinding −150 mesh for clean liberation of the iron oxide from the gangue.

Magnetic iron content of the crude ore ranges from 18 to 28 pct and the average analysis as indicated by drill hole records is shown in Table I.

Ore is extremely hard and no standard type of drilling equipment has been able to do a satisfactory job. The problem has been overcome by using jet piercing method of drilling the ore for blasting. Broken ore is loaded by 5-yd shovels into 22-ton trucks for haulage two miles to the coarse crushing plant and the start of concentration.

Clearing and stripping of the mine was started about the middle of 1951 and the mine was opened and the main haulage road to the crushing plant

OSCAR LEE is Preparation Engineer, Reserve Mining Co., Cleveland. This is an abstract of an article which appeared in MINING ENGINEERING, May 1954.

was completed early in the summer of 1952. The crushing, concentrating, and pelletizing plants were first turned over in August 1952, and production of concentrate and pellets started soon thereafter.

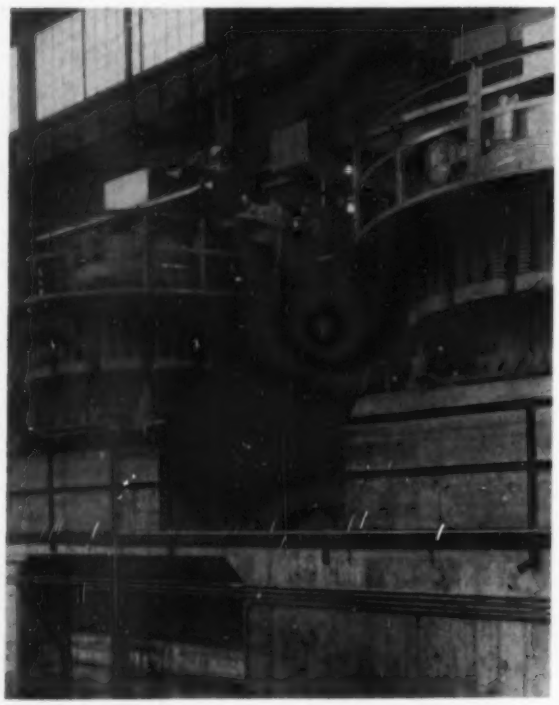
The mine and the crushing plant are operated one shift per day and produce an average of 3000 gross tons of crushed ore per shift. The mine-run of ore containing a relatively small amount of fines and a heavy proportion of large blocks is dumped from the 22-ton trucks directly into the top of the 42-in. gyratory crusher which discharges through a chute into a 30-in. gyratory crusher. The ore tends to break into slabby pieces. The crusher product together with the ¾-in. screen undersize is conveyed to the mill storage bins.

Concentrating Plant

Two concentrating plant storage bins carry a 24-hr supply for the mill operation. The 10 ft 6 in. x 14 ft 7-in. rod mill operates in open circuit and at a speed of 15.5 rpm (64 pct of critical). The normal rod load for a 130 gross tons per hr feed is 85 tons, and the maximum size rod is 4 in. The pulp density is maintained at 73 to 75 pct solids.

The first stage of concentration is on the rod mill discharge. Two 36x42-in. magnetic cobbers handle the full load of up to 135 to 140 tons per hr and, depending upon the grade of the crude ore, remove from 35 to 45 pct as a low grade tailing. The cobber concentrate flows directly to two 10½x12-ft ball mills operated in closed circuit with magnetic separators and 54-in. duplex spiral classifiers.

The ball mill discharge flows by gravity to the second stage of magnetic separation on two banks of three separators each. From 15 to 20 pct of the primary mill feed is eliminated as tailing and the rougher concentrate is pumped to spiral classifiers,



These 7-ft cone crushers in series reduce taconite from 3 1/5 in. to 1½ in. and from 1½ to ¾ in. Final product from cone crushers is rod mill feed.

Table I. Analysis of Ore Based on Drill Hole Records

Constituent	Pct
Total Fe	32.0
Magnetic Fe	24.5
SiO_2	45.2
Mn	0.3
Al_2O_3	0.8
CaO	2.3
MgO	3.0
P	0.05
S	0.02
TiO_2	Trace

one for each ball mill, after passing through demagnetizing coils It is important that the classifier overflow shall carry 80 to 85 pct of —325 mesh size solids. The classifier sand is returned to the ball mills and normally this represents a cirulating load of about 75 to 150 tons per hr.

The total power consumption for grinding from ¾ in. to 80 to 85 pct —325 mesh in the rod and ball mills is under 11 kw-hr per gross ton of primary feed. The total steel consumption of rods and balls per gross ton of ¾-in. mill feed is less than 1.5 lb per ton.

The classifier overflow is remagnetized on the way to two 16-ft diam hydroseparators to which wash water is added. The overflow is a clean tailing and the thickened sludge is delivered by diaphragm pumps to the final stage of magnetic separation. The concentrate from the magnetic finishers goes to two 16-ft diam hydroseparators and then to an 8x10-ft vacuum filter.

This fine grinding and magnetic concentration flowsheet was developed by the Mines Experiment Station of the University of Minnesota as the result of many years of research and experimentation. The Babbitt plant metallurgical results check the laboratory results closely.

Various types and combinations of single drum magnetic separators with wash boxes, two drum machines, and belt machines are being tried in both the rougher and finisher circuits . The grade of the final concentrate averages about 64.5 pct Fe with a production of 1000 gross tons or more of concentrate per 24 hr and with a magnetic iron recovery of 90 pct. Ratio of concentration is 3:1.

The filter operates with a vacuum of 24 to 25 in. and at a speed of from 51 to 55 rph. It has produced over 65 short wet tons of filter cake per hr at 10.25 pct moisture. The plastic filter cloth now in use has a life of well over 3 months.

Total mill tailing flows by gravity to the tailing pond. On the way, however, the coarse tailing is removed in a hydroseparator, the overflow of which flows to a 150-ft thickener. The sludge from the thickener joins the sand product of the hydroseparator and then goes on to the pond. The thickener overflow is pumped back to the concentrating plant for reuse. The total water consumption in the mill is about 7500 gpm, of which 3000 gpm is fresh makeup water obtained from Birch Lake. An ample supply of clean water is an important requirement to produce the best grade of concentrate. Table II gives a typical concentrate analysis.

Pelletizing Plant

Various methods of agglomerating taconite concentrate have been tried over the years, but because of the extreme fineness of the particles, 85 pct —325 mesh, the pelletizing process was developed by the

Table II. Typical Concentrate Analysis

Constituent	Pct
Fe	64.55
SiO_2	9.2
CaO	0.53
MgO	0.67
Al_2O_3	0.55
Mn	0.22

University of Minnesota Mines Experiment Station not only to overcome these difficulties but to make use of the physical condition of the material.

When properly made from magnetic taconite concentrate, the final burned pellets consist largely of hematite and have a porosity of 30 to 32 pct. They make an excellent blast furnace material and are strong enough to stand up well in transportation.

Babbitt has four rectangular shaft pelletizing furnaces, each with a capacity of 250 gross tons of pellets per day. Each furnace has its own balling drum.

To make the desirable strong, round pellets for feeding to the furnace, it is very important that the moisture content of the filter cake be under control. Normally the moisture should run between 10.0 and 10.25 pct. To further assist in making good green pellets, from 7 to 10 lb of bentonite binder per ton of concentrate is added prior to feeding the concentrate to the balling drum.

The balling drum is 7 ft in diam 16 ft long with a slight downward slope from the feed to the discharge end. The concentrate builds up its own lining and continually operating leveling bars keep the lining in proper condition for the best rolling action of the balls.

Balling drum discharge is screened on 2 ft 6 in. x 6-ft vibrating screens, the −⅝-in. product of which is conveyed back to the feed end of the drum and serves as seed pellets. The screen oversize is delivered to the top of the pelletizing furnace by a distributing belt conveyor, motivated by a pantograph device. This system spreads the pellets uniformly over the entire cross-section of the furnace.

The heat for pelletizing is supplied by adding about 1 pct anthracite coal to the concentrate and by the additional use of 2 to 2½ gal of oil per ton, burned in combustion chambers along the two long sides of the furnace. The coal is added to the concentrate sludge ahead of the filter.

Air is blown into the lower part of the furnace to cool the pellets before discharging and also to maintain an oxidizing atmosphere in the furnace. As a result, the magnetite is oxidized to hematite with an exothermic reaction and the heat thus developed supplies approximately one third of the total pelletizing heat requirement. The temperature in the critical zone is 2300 to 2350°F and the pellets discharge from the furnace at a temperature of 200°F.

Table III. Typical Pellet Analysis

Constituent	Pct
Total Fe	62.48
Ferrous Fe	5.00
SiO_2	9.00
CaO	0.50
MgO	0.65
Al_2O_3	0.54
Mn	0.22
P	0.023

Mine and crushing plant produce 3000 tons per day, operating one shift per day. Primary 42x65-in. crusher with 300-hp motor reduces run-of-mine ore to 7½ in. A 30-in. crusher completes reduction to 3½ in. Mine-run ore, containing little fines and major proportion of large blocks, is dumped directly into 42-in. crusher from 22-ton trucks.

The pellets are delivered to a vibrating screen located on top of the railroad loading bin. The fines and dust are ground in a 4x6-ft ball mill and returned to the same filter which filters the concentrate. The pellets delivered to cars for shipment range in size from ½ to 1-in. diam and have a porosity of 30 to 32 pct. They are hard and strong and show little or no deformation or shrinkage during burning. They weigh from 112 to 117 lb per cu ft. Table III gives an analysis of the pellets.

Future Operations

The Babbitt plant, in capacity, represents one section of the new project already under construction at East Beaver Bay on Lake Superior. The initial plant, consisting of 12 sections with an annual capacity of 3.75 million tons of concentrate, is scheduled for completion by the fall of 1957, although the first eight of these sections should begin operations late in 1955.

The plant at East Beaver Bay will be known as the E. W. Davis Works in honor of E. W. Davis who, as director of the Mines Experiment Station of the University of Minnesota for over 35 years, developed the basic methods of concentrating and pelletizing taconite ore.

The Reserve Mining Co. project will ultimately reach a capacity of 10 million tons of high grade concentrate per year. In addition to the crushing and beneficiating plants, the company is building its own 47-mile interdepartmental railroad between the coarse crushing plant at the mine and the fine crushing plant at East Beaver Bay. The program also includes construction of a harbor and dock, power plant, and modern townsites at Babbitt and East Beaver Bay.

Journal of Metals Award Paper

Fig. 1—The sintering plant of the Tennessee Coal & Iron Div. has three 72-in. Dwight-Lloyd machines.

Sinter Is What You Make It

by E. H. Rose and D. J. Reed

SEEKING to establish quality criteria and control for iron ore sinter produced in its central ore conditioning plant on Red Mountain, the Tennessee Coal & Iron Div., U. S. Steel Corp., undertook a modest research program beginning in 1950. This article is in the nature of a progress report and will concern itself mainly with novel features of instrumentation which had to be developed in order to attain a reasonable degree of success.

When originally built in 1940 the sintering plant, shown in Fig. 1, had only the conventional control instruments common to most such plants. These were windbox thermocouples, draft gages, ignition gas flowmeter, and a speed recorder for each of the three 72-in. Dwight-Lloyd machines. Measurement of the quality of sinter made was limited to standard chemical and screen analyses.

Prior to inaugurating research to improve sinter quality it was conceived that tests, other than those obtained by conventional measurements, would be necessary. As the first step, a new testing laboratory was established to study the physical and chemical properties of sinter. This was patterned after the facilities already in use for research purposes in the Oliver Iron Mining div. of the corporation, for which great credit is due the late Walter Maxson.

This laboratory is believed to be the first to function in conjunction with and contiguous to an operating plant. Initially, facilities were provided to measure macro- and micro-porosity, reducibility in hydrogen under standard conditions, FeO content, and physical strength. These determinations were made periodically on shift composite samples. Determination of magnetic content was soon added to the list using the Davis tube after grinding of the sinter. Modifications have been worked out to minimize the time requirement, but at best these tests are still laborious and slow.

To begin with, it was obviously necessary to determine what particular properties of sinter are most important in relation to subsequent blast furnace performance. Then it would be desirable to seek some means of continuous measurement of such

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properties by means of instrumentation designed or adapted for the purpose. A further thought was that even if a given property could not be monitored directly and continuously, there might be some other property related to the first in such a way as to act as an indicator or marker for it. If the second could then be instrumentized, the first would presumably be monitored effectively even if indirectly. For example, tumbler or shatter tests for sinter strength could hardly be adapted to function continuously on the production line, but there might be some other property amenable to instrumentation which could be utilized for the same end purpose if its relationship to strength were sufficiently close and direct.

Soon after the laboratory was set up other tests were added to those mentioned, as techniques for them were developed, without knowing at the time what the significance of any of them might prove to be. Among these were determinations of the free residual carbon, the metallic iron in finished sinter, and the lime in its three separate forms as oxide, carbonate, and silicate. Early in the laboratory program, a card system was set up with a separate card recording the simultaneous values of all of the properties determined for any given sample of sinter.

From the blast furnace viewpoint, most operators agree that strength and freedom from fines are the most important properties of sinter. In fact, to achieve these properties is the fundamental reason why sintering is practiced at all. Among sinter plant operators, FeO content has long been regarded as a rough index of sinter strength. However, the analytical methods for FeO are rather tedious, and concordant results are difficult to obtain.

Apart from such metallic iron as may be present, the component of highest magnetic permeability in ferrous sinter is the magnetic oxide, Fe_3O_4. This is sometimes written as $FeO \cdot Fe_2O_3$ to indicate the ferrosoferric oxide. In this case, metallic iron does not exceed 0.1 pct. Magnetite, most of it formed during the sintering operation, is the only magnetic component present in significant quantity.

In due course enough cards were accumulated to permit a rough statistical analysis. It was found that there is a close relationship between chemically determined FeO and the percent of magnetic material in finished sinter.

This relationship is shown in Fig. 2. As may be seen, there is some scattering of individual points. This is certainly due in part to the unreliability of the FeO determination and in part to a carry-over of gangue with the magnetics in the Davis tube because of the inability of fine grinding to effect complete liberation. It has been found, however, that there is a small but significant amount of FeO remaining in the nonmagnetic Davis tube reject. A run-down of this fact ought to tell something about iron tied up as ferrous silicates or ferrites.

When this relationship was found, it was recognized as possibly being one of the markers looked for. If the analytically determined FeO content is an index of sinter strength, and the FeO is present almost entirely as a component of the magnetic oxide, then it was possible that the magnetic content might also be an index of strength. Furthermore, it should be possible to monitor the magnetic content or the magnetic permeability of sinter continuously which is something that could hardly be hoped for in the case of FeO itself.

To be practical, an instrument for measuring magnetic permeability of the sinter would have to

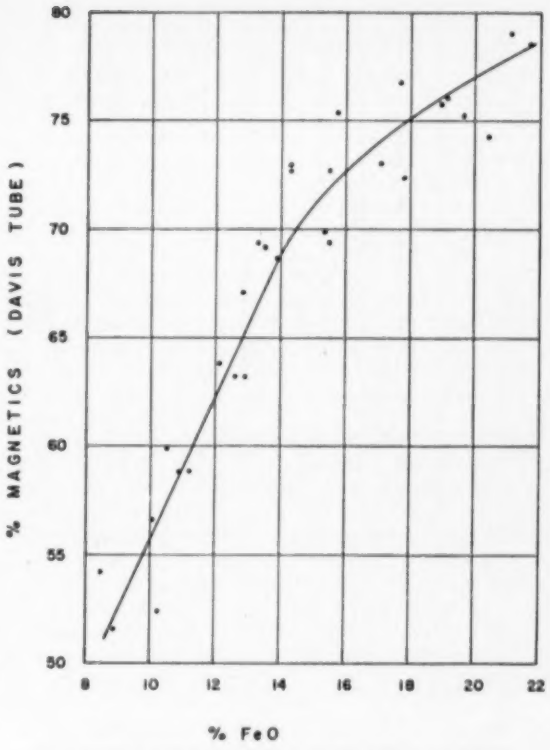

Fig. 2—The close relationship in the finished sinter between chemically determined FeO and the percent of magnetic material is shown.

be applied directly to the beds of the sintering machines. No such instrument was known to be available. It became necessary to design one. The electrical laboratory developed an instrument for the purpose which has been in experimental use on one sintering machine for several months with satisfactory results. The remaining two sintering machines in the plant are to be similarly equipped.

Magnetic Permeability Meter

The sinter magnetic permeability meter consists of a cylindrical scanning element electrically connected with a cabinet mounted energizing and metering unit. The scanner, located near the discharge end of the sintering machine, rests directly on the cool surface of the sinter bed. Being axle mounted, it is free to rotate as the bed passes beneath it and to adjust itself to changes in height of bed, but is prevented from travelling out of position by means of a hinged yoke, one end of which is anchored. The metering unit rests on the floor nearby.

The scanner is a bridge circuit of four identical coils, each consisting of three loop antennae. Two of the coils are placed together and electrically balanced slightly above the sinter bed. The other two coils are balanced in air above the first two coils, but in the same magnetic field as the bottom pair. As the sintered material passes under the bridge, a change of inductance results in the bottom two coils, the amount of unbalance depending on the amount of Fe_3O_4 and metallic Fe present in the field. Since the amount of metallic iron is almost always insignificant, the bridge output is proportional to the Fe_3O_4 content.

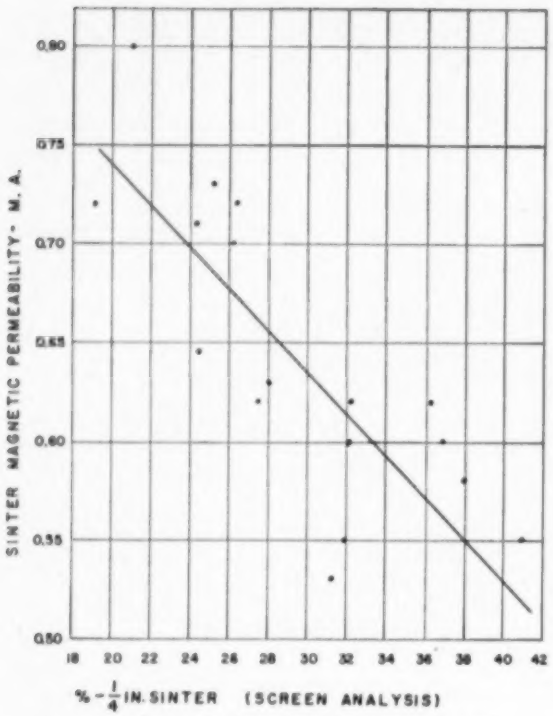

Fig. 3—A good correlation was found between the meter values for a given period and the screen analysis of total production of sinter.

The sinter testing laboratory has run tumbler tests and Davis tube magnetics on samples of known permeability recorder readings, with results shown in Table I.

The correlation between the meter, the Davis tube check tests, and the sinter strength shown by tumbler tests is evident from Table I. Furthermore, although a recorder is in use on only one of the three sintering machines, a good correlation has been found between the meter values for a given period and the screen analysis of total production of sinter as received at the blast furnaces during that time. This is not unreasonable to expect, because all three machines work on the same feed, which is divided between them by a rotary splitter after the total mix has passed through primary and secondary pug mills. The relationship is indicated in Fig. 3.

If magnetic permeability can be accepted as a valid index of sinter strength, a continuous minute-to-minute permanent record of that property, without the attendant sampling and laboratory lag, is of great value not only to the operators but to supervision and management as well.

From present experience it cannot be determined that this device would be applicable to operations where the material to be sintered is entirely in the form of magnetite to begin with. None of the Alabama ores used in this plant contain any magnetite. However, up to 10 pct of the burden may be Swedish magnetite ore. Also, about half the iron oxide in the blast furnace flue dust used as sinter plant fuel is in the form of magnetite. That the screen analysis of sinter received at the blast furnaces can be correlated with the permeability readings indicates that magnetite in the raw mix is not a factor.

Magnetite in grizzly undersize circulating on the machines themselves is, however, another matter. It has been noted that the *amount* of return fines is inversely proportional to the meter reading. As an example, the depth of return fines in the vibrating conveyor handling returns were 5½, 5, and 3½ in. respectively for permeability recorder readings of 0.4, 0.5, and 0.7 ma. This is not an anomalous behavior. A sinter giving a low meter reading is weak and friable. Consequently there is more breakage when it strikes the grizzlies with corresponding increase in returns. Conversely, high readings mean less breakage and less returns.

Stack Gas Analysis

Present research aimed at automatic control is concerning itself with breaking complex variables down into their components. For instance, continuous instruments for stack gas analysis should shed light on the combustion reactions. The content of CO and combustibles would tell something of the water gas reaction. Free oxygen, which is already known to vary widely, presumably does so mainly as a function of wind leakage which in turn is related to bed porosity. If there were no lime in the ore, the CO_2 content would tell how much carbon had completely burned. However, in this case, Alabama red ore contains about 25 pct $CaCO_3$ which calcines at the sintering temperature and would invalidate the CO_2 readings for the intended purpose. This portion of the research program is still in a formative stage. There is nothing definite to report.

Recording Pyrometer

Many operators have remarked that a quick method of determining carbon in raw sinter mix would be an invaluable control tool. One suggestion was that a heavy liquid separation made on samples taken at the swinging spout would quickly reveal the amount of free carbon present. Unfortunately coke, and especially coke present in flue dust, contains prodigious quantities of entrained gas. Heavy liquid separations cannot be made because of bubbling in the separatory vessel. Evacuation at reduced pressure will not cure the trouble. Even under those conditions gassing will continue for an hour or more.

This, in other words, was one of the trials and errors. Again on the principle of looking for a marker that could be instrumentized, a recording radiation pyrometer was set up to measure surface temperature at the exit side of the ignition zone. The ignition furnaces use natural gas of uniform Btu value. The flow rate is accurately controlled. As in most plants, the surface of the bed is incandescent for a few inches after leaving the ignition zone. However, ignition having already been completed,

Table I. Effective Range of Variables for Magnetic Permeability Recorder Full Scale Deflection

Sinter Magnetometer MA	Sinter Magnetics, Pct (Davis Tube)	Tumbler Test Pct —3M
0.0 to 0.2	41.9	86.5
0.0 to 0.2	41.4	87.7
0.2 to 0.3	43.5	82.2
0.4 to 0.5	44.5	90.3
0.5 to 0.6	53.7	60.0
0.5 to 0.6	53.1	76.4
1.0	70.4	60.3
1.0	67.7	52.7
1.0	74.6	35.0

the surface would go black at once but for the burning of top-layer carbon. In that narrow area of incandescence, which also has completely free access of air, the temperature is therefore related to the carbon content—if the time element is assumed to be a constant (which it is for any given pallet speed) and for mixing to have been uniform.

Accordingly, a recording pyrometer was focussed on a point as close as possible to the ignition zone, choosing for the purpose the same sintering machine on which the recording magnetometer was in use at the discharge end. After a sufficient period of time, it became possible to correlate the pyrometer values at the ignition end with the magnetometer values at the discharge end. It was evident that they are telling what amounts to the same story. Fig. 4 shows the relationship that has been found between them. As in Fig. 2 showing the FeO magnetics relationship, there is some scattering of points but the trend line appears to be valid. The pyrometer is simply measuring the aggregate effect of several variables, among which carbon content is the predominant, but not the only, one. For example, excessive moisture with the same carbon content (as determined analytically) decreases both the initial surface temperature and the sinter magnetics but the respective changes in them is not a precise proportion.

Even though they both give essentially the same information, it would appear that the ignition zone pyrometer would be preferable to the magnetometer as a means of controlling fuel feed rate, simply because it is at the head end of the machine and hence gives a much quicker response. In fact, it was soon noticed that the pyrometer was reflecting the effect of bin hang-ups.

It can now be inferred, though not completely proved, that it is mainly the carbon content of the mix which has the greatest influence on the strength of finished sinter, assuming adequate air supply but with moisture running a close second. This follows from the facts that: A—The magnetometer readings have already been equated to strength, B—the magnetometer and pyrometer readings are concordant, and C—the pyrometer reading is essentially a measure of the combined effects of moisture and carbon.

In due course, ignition zone temperature will be incorporated in the card system previously mentioned. By this means, it should be possible to detect other relationships between it and the laboratory determinations of various other sinter properties.

Draft Gages

About three years ago, fly ash arrestors were installed ahead of the sinter plant fans, and more recently Cottrell precipitators beyond the fans. Draft gages on the sinter bed and across the fly ash arrestors and Cottrells are very useful in determining bed porosity and air leakage. As the bed becomes more compact, the bed draft gage reading increases while the gage reading across the arrestors and Cottrells decreases. The drop across the fly ash arrestor can be calibrated quite closely to air volume. There is even some indication of an influence by it upon sinter strength as indicated by the magnetometer, though within limits a minor one as compared with carbon content. Fig. 5 shows the correlation between the drop across the fly ash arrestor and the average bed differential, or the relation of air flow to bed vacuum. For conditions here, it has been found that sinter of reasonable strength cannot be made when readings across the arrestor are below 0.7 in. of water. When that occurs the fault is usually found in abnormally packed bed, insufficient water addition, or clogged grate bars.

Water Addition Flowmeter

A recording instrument to give instantaneous readings of moisture in sinter mix is something the industry should be crying for—and a few of its practitioners are. No such instrument is presently available. Several investigators elsewhere are known to be working on the problem. It is improbable that continuous direct measurement will prove feasible, although an ingenious device has recently become available for quick manual determinations. This depends on the pressure developed by acetylene in a closed system when calcium carbide is added to a measured sample.

The marker principle would seem more promising. Dielectric properties are known to be related to moisture content and indeed are used in the paper industry for moisture control. The outlook for application of this principle to measurement of moisture content of sinter mixes is less bright because of magnetic properties of the minerals themselves although a particular frequency band may be found which is sufficiently selective for a given application. In selected bands of the light spectrum photo principles might be applied. These are by no means the only principles that might be considered.

Ignition Gas Flowmeter

An ignition gas flowmeter on each machine permits the operators to control gas flow rate accurately. Since ignition serves only to dry the top surface of the bed and ignite the carbon the flowmeter precludes excessive use of gas. The amount of

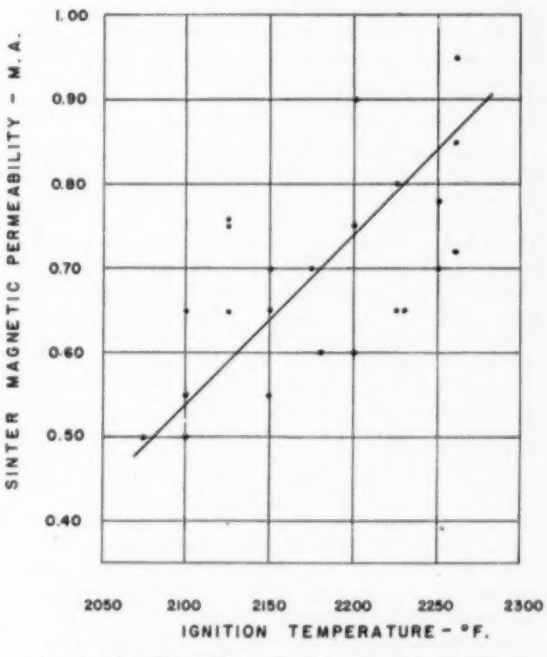

Fig. 4—The relationship is shown between the pyrometer values at the ignition end and the magnetometer values at the discharge end.

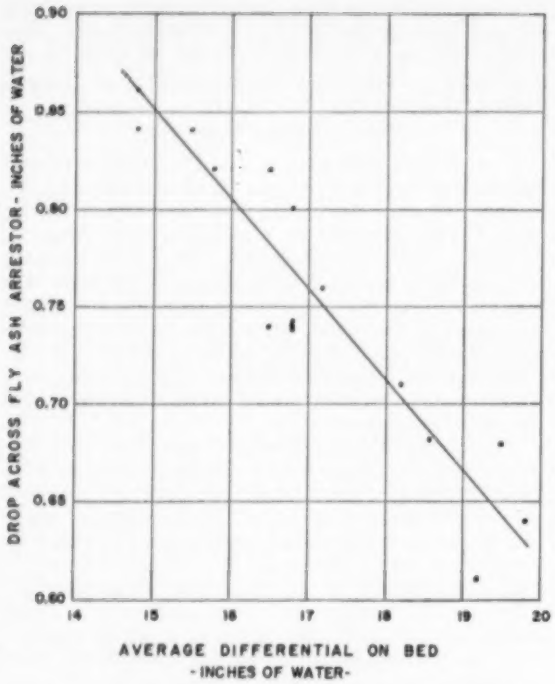

Fig. 5—A correlation was demonstrated between the drop across the fly ash arrestor and the average bed differential or the relation of air flow to bed vacuum.

ignition gas must also be controlled to the point where the bed surface is not completely fused or slagged over after ignition. We expect that the gaseous combustion products resulting from ignition will not seriously interfere with interpretations of information later to be obtained from continuous stack gas analysis instruments. The quantity is relatively small and constant.

Other Instruments

In addition to those that have been discussed, some additional instruments are used in the plant for control purposes. Among these are windbox thermocouples, machine speed recorders, and fan motor ammeters. Since they are standard instruments common to most sintering plants, they will not be discussed. Suffice it to say that all of them contribute to experimental plant studies which are being made to integrate knowledge of the influence of various operating variables upon the quality of sinter. Among such studies are the interdependency of bed depth, machine speed, particle size of carbon, fan power consumption, and vertical burning speed through the bed.

Future Research

This paper is intended to be only a progress report. When the research program began in 1950 it was necessary first to devote something over a year to finding out what to measure and how before the long and tedious process of interpreting new knowledge could begin. Moreover, the relative urgency of various blast furnace problems has to be considered. Of these, the problem of excessive fines in furnace burdens was the most acute. The source of these fines was by no means exclusively in the sinter. Extensive studies, not pertinent to the theme of the present paper, have concurrently been in progress in the crushing and screening sections of the ore conditioning plant. The share of fines contributed by sinter had nevertheless to be reduced.

For that reason attention was concentrated upon the factors influencing sinter strength as has been described. Even a part of that story has been omitted, as not being of general interest, although it has consumed a large part of the laboratory time. Red Mountain ores are high in lime, a condition not commonly met elsewhere in this country. Since the calcium carbonate inevitably decomposes at the sintering temperatures, a major necessity is that as much as possible of the resulting CaO should combine with the free silica in the ore, during the sintering operation. Otherwise, it hydrates during water quenching and in the relatively humid Alabama climate whereupon the sinter simply falls apart in a few hours. Yet the slagging of lime interferes with bed porosity and hence is something to be reckoned with in plant control. Even worse, as a function of temperature dicalcium silicate undergoes several polymorphic inversions involving volume changes.

From the blast furnace viewpoint, ease of reduction or reducibility is the property of sinter regarded by many as second only to strength in importance. The original reducibility apparatus in the testing laboratory was based on the rate of evolution of water vapor when sinter is reduced in hydrogen under standard conditions. It is a long and tedious determination, requiring frequent weighing and is limited to very small samples. This was soon replaced by an apparatus which directly measures the loss of weight of the sinter sample itself. This accommodates a much larger sample and the determination can be shortened by the necessity for frequent weighing remains. An apparatus is presently being designed in which the loss of weight will be recorded on a chart without operator attention.

In the meantime, reducibility determinations have been discontinued, but enough of them have been made to confirm the findings of other investigators, namely that reducibility is inversely proportional to strength. To obtain the optimum in the one has required a sacrifice in the other. It does not follow, however, that this is inevitable or that a technique cannot be found to yield optimum values in both. Studies aimed at that objective will be undertaken when the new apparatus becomes available.

Sintering is in itself a far more complicated process than might superficially appear. When considered in relation to raw materials on the one hand and blast furnace operation on the other the area of useful research that could be done is vast indeed. The time will come when some of the major mysteries are cleared up. It is believed that extension and development of instrumentation will speed the day. As has been shown, some vital elements of sintering whose significance had not even been suspected can be resolved by that means. From the sintering viewpoint, however, the job will never be complete until the devious intricacies of blast furnace operation are likewise resolved, so that the sinter man can know by precise definition what specifications his product is to meet. That situation can be reached only when the blast furnace man is similarly provided with adequate instrumentation.

Reverberatory Furnace Practice at Noranda

by J. N. Anderson

Developments in reverberatory furnace practice at Noranda over the period 1928 to 1953 are described. Features of interest are increasing furnace tonnage from 700 to 2000 tons per furnace day, the use of the suspended basic roof, and improvements in furnace fuel ratio. Points of comparison and contrast between Canadian and American furnace practice are given.

OPERATIONS at the Noranda smelter have been described in a series of papers published between 1930 and 1945.[1-4] In the present paper the development of reverberatory furnace practice over the 25 year period from the beginning of operations up to the present time will be reviewed and current furnace practice will be described in some detail. Particular attention will be given to those features which are characteristic of Canadian practice: first, the use of the suspended basic roof; second, the deliberate driving of furnaces to give tonnages in the range of 1400 to 2000 tons of solid charge per furnace day; and third, the continuous operation of furnaces at high tonnage for many years without any extended shutdown for repairs or rebuilding. Finally, points of comparison and contrast between reverberatory furnace practice in Canada and the United States will be discussed.

The Noranda smelter, which started in December 1927, was built for the reduction of ore from the Horne mine where early development had shown a comparatively small tonnage of rich copper-gold ore of a grade and character which would require direct smelting. The smelter was designed for a capacity of 1000 tons of ore a day and originally consisted of eight roasters, two reverberatory furnaces, and two converters, together with necessary auxiliaries. The discovery of a large new body of ore in 1928 made it necessary to increase both the size and the scope of the reduction plant. A mill which was ultimately brought to a capacity of 3000 tons a day was built for concentrating low grade ore and in addition the capacity of the smelting plant had to be greatly expanded, so that for the next fifteen years every effort in the smelter was directed toward achieving maximum tonnage. Because the layout and design of the smelter made it impracticable to add a third furnace, it was necessary to increase the tonnage on the two original furnaces by improvements in furnace design and operation, roasting and converting equipment being added as required to meet the demands of increased furnace capacity. The smelter tonnage, which reached a peak in 1941, was curtailed in 1944 when it became necessary to operate on a one-furnace basis because of a reduction in the output of the Horne mine due to a shortage of labor. Two-furnace operation at a moderate tonnage was resumed in 1949.

In the early years the smelter tonnage was made up almost entirely of Noranda ores and concentrates. However, since 1937 an increasing tonnage of ores and concentrates from other mines has been treated in the smelter. In recent years, with decreased production from the Horne mine, copper concentrates from several mines in the district, treated on a custom basis, have formed an important part of the smelter tonnage.

A review of developments in reverberatory furnace practice at Noranda falls naturally into the following four periods: 1—1928 to 1935, the early years; 2—1935 to 1944, the period of greatest change and development; 3—1944 to 1949, one-furnace op-

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Discussion on this paper, TP 3709D, may be sent, 2 copies, to AIME by Aug. 1, 1954. Manuscript, July 20, 1953. Los Angeles Meeting, February 1953.

The Transactions papers appearing in the Journal of Metals during 1954 will subsequently appear in AIME Transactions Volume 200, and may be permanently referenced to that volume.

Table I. Roaster Feed

Material	Tons per Day	Analysis						
		Au, Oz per Ton	Ag, Oz per Ton	Cu, Pct	SiO_2, Pct	Fe, Pct	S, Pct	Zn, Pct
Smelting ore	1614	0.17	0.3	1.7	24.4	35.4	25.9	0.1
Noranda concentrates	372	0.69	1.2	11.6	2.1	41.5	39.8	0.2
Custom copper concentrates	685	0.59	6.7	20.9	4.1	31.2	32.5	3.9
Other ores and concentrates	30	0.59	59.2	19.3	17.0	14.7	2.0	4.7
Siliceous fluxing ore	338	0.15	0.1	0.0	71.8	4.8	1.5	—
Reverts	5	0.16	1.4	4.8	26.0	30.2	2.2	—
Total feed to roasters	3044	0.33	2.4	7.2	22.3	31.6	26.1	1.0
Calcine produced	2764						14.7	

eration at 2000 tons a day; and 4—1949 to 1952, current practice.

The period 1928 to 1935 was marked by an increase in furnace tonnage from an initial rate of 700 tons of solid charge per furnace day to 1250 tons a day. The chief factors which contributed to this improvement were as follows:

1—The use of secondary combustion air at pressures in the range of from 5 to 10 psi to obtain quick complete combustion and maximum flame temperatures.

2—The increasing of the combustion area of the furnace near the firing end. This was the initial step toward a furnace design planned for efficient combustion of fuel and utilization of heat, which it since has been possible to develop and perfect more fully by the use of the suspended roof.

3—Preparation of the roaster charge and operation of the roasters to produce fine hot charge for the furnaces.

The original furnace roofs were, of course, sprung arches of silica brick. In 1930 as furnace tonnages were increased to 900 tons a day, arch life for sections close to the firing end was only 100 days and the frequency and the cost of arch repairs were becoming a problem. This was met by the use of "shoulders" of magnesite brick extending about 40 in. from the skewback, some improvement also being effected by the use of better designed silica brick shapes for the main part of the roof. However as the furnace tonnages were increased to the range of 1250 tons a day and with a greater burden of concentrates which gave a finer charge, much of the advantage gained from the use of magnesite shoulders was lost. By 1935 it was apparent that some improved method of roof construction was necessary before furnace tonnage could be further increased. The solution was found in the suspended basic roof, the use of which had been pioneered in 1933 by the Hudson Bay Mining and Smelting Co. at the Flin Flon smelter. The first trial of this type of roof at Noranda, made early in 1935, marked the beginning of a new era in furnace practice.

In the period of 1935 to 1944 there were a number of changes and developments which led to increased furnace tonnage and to improved fuel ratio. The peak furnace tonnage for the period was in March 1943, with 1600 tons of solid charge per furnace day and a fuel ratio of 10.3 pct, as compared with 1270 tons of solid charge and a fuel ratio of 10.9 pct for the best month during the years 1928 to 1935. Perhaps the most important developments which led to this improvement were as follows:

1—The use of the suspended basic roof.

2—The lengthening and the widening of the furnaces.

3—Changes in the coal plant which gave drier, more finely pulverized coal and provided better control over the rate of firing.

4—Improvements in roaster practice, particularly with respect to the handling of roaster Cottrell dust, which gave a better and a more uniform furnace charge.

At first the use of the suspended roof was confined to the firing end of the furnace, but by 1940 it was being used throughout the length of the furnace, and also for the roof of the uptake and the outlet flue. With the entire roof suspended and by using "hot patching" methods for repairs, long furnace campaigns without shutdowns for roof or other furnace repairs became possible. A further advantage found with suspended construction was that it made practicable a roof contour designed for efficient combustion of fuel and utilization of heat.

In 1937 both furnaces were lengthened by about 9 ft, the primary object being to permit increased furnace tonnage without adversely affecting slag losses. This change also reduced the length of the converter slag launder and made it possible to use larger ladles previously impracticable because of

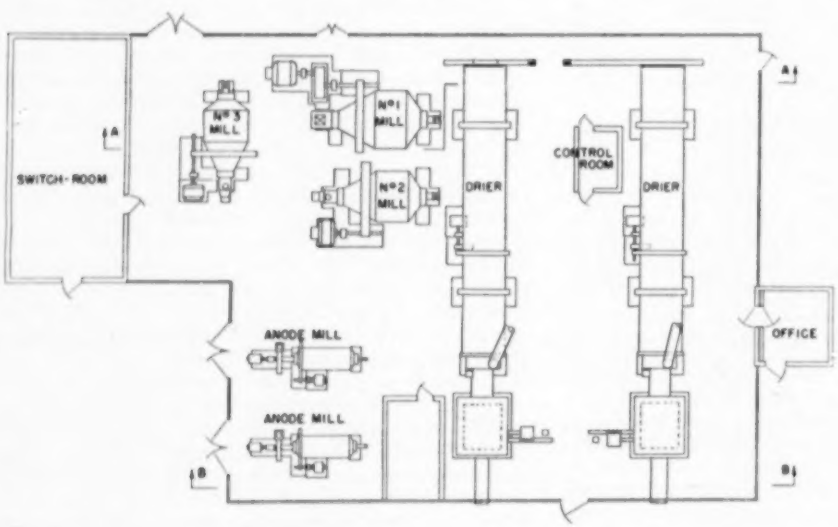

Fig. 1—Floor plan of coal plant.

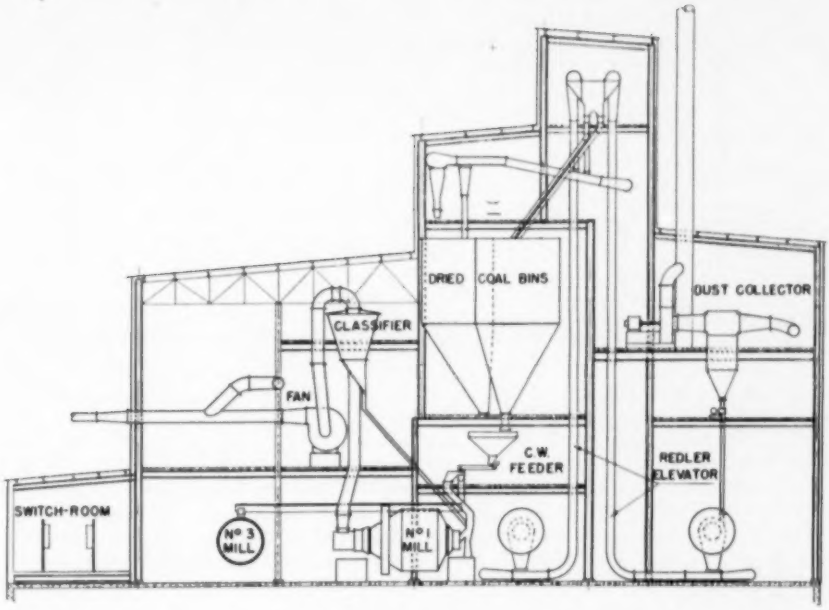

Fig. 2—Section through coal plant at *A-A*, Fig. 1.

lack of headroom in the converter aisle. In 1941 both furnaces were widened in order to provide a wider clear channel in the center of the furnace for the free flow of matte and slag to the skimming end of the furnaces. This widening of the furnaces, which has been described,[4] was accomplished with little interference to normal furnace operation. It is worth noting that without the suspended roof the furnaces could not have been widened because a sprung silica arch would not have been practicable for the wider span.

In 1943 a shortage of labor, particularly of miners, made necessary some reduction in smelter tonnage and early in 1944 it was found that a further considerable decrease in tonnage had to be made. It was decided to shut down one furnace and to operate the smelter on the basis of one furnace at maximum capacity until conditions permitted a resumption of two-furnace operation. This period of one-furnace operation extended from June 1944 to July 1949, and during this time No. 1 furnace operated at an average tonnage of 1910 tons of solid charge per furnace day. The peak month was April 1946 with 2160 tons per day and a fuel ratio of 10.4 pct.

The story of how the furnace tonnage was pushed to this record level has been told[4] and need only be briefly mentioned here. It was of course necessary to raise the roof of the furnace to provide the necessary combustion area for burning 200 tons of coal a day. There were difficulties due to bottom "build-up" as well as the physical problems of handling greater quantities of matte and slag. Once these troubles had been overcome the furnace operated as smoothly at 2000 tons a day as it had at 1500 tons a day, with little or no change in fuel ratio and no apparent increase in slag losses. Roof repairs were perhaps double what they were at the lower tonnage rate, but there was no difficulty in maintaining the furnace roof by the regular methods of patching.

In 1949 it became possible to resume normal tonnage from the Horne mine and in addition, two new base metal mines in the Rouyn-Noranda district were scheduled to come into production in 1949 with an output of some 350 tons of copper concentrates a day. As a result the total tonnage available for the smelter was considerably greater than could be handled through one furnace, and it was therefore necessary to resume two-furnace operation. It was known that the tonnage to be smelted would amount to about 1400 tons of solid charge per furnace day, which by past standards could only be rated as a "moderate" tonnage. It was decided to modify the contour of the furnace roofs with the object of obtaining the maximum fuel economy and the most efficient operation at the necessary rate of firing, which was expected to be about 140 tons of coal a day. In making No. 2 furnace ready for operation the roof therefore was completely rebuilt; also, advantage was taken of the opportunity to rebuild part of the side walls and to dig out the bottom of the furnace at the skimming end to the level of the tapholes. When No. 2 furnace was started in July 1949, No. 1 furnace was shut down for a similar roof rebuild. No. 1 furnace went back into operation in August and since that time the smelter has operated regularly on a two-furnace basis.

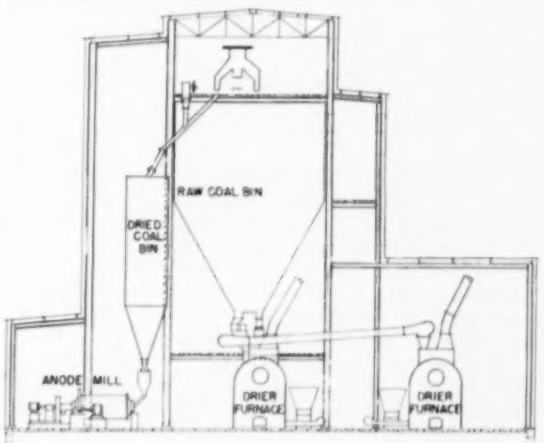

Fig. 3—Section through coal plant at *B-B*, Fig. 1.

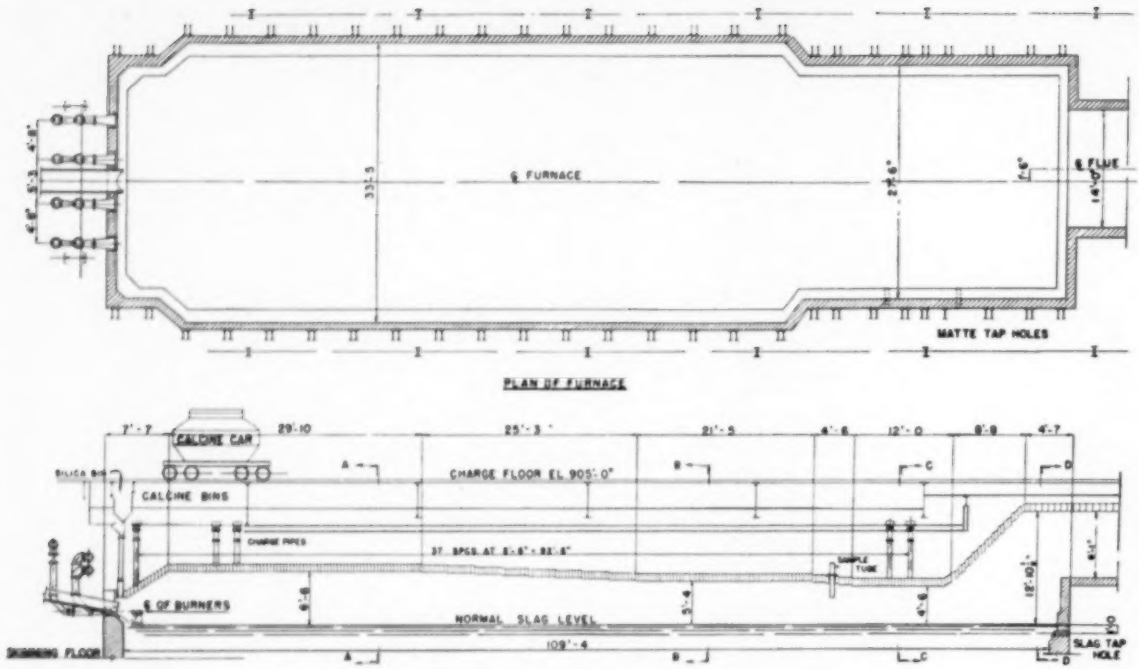

Fig. 4—Plan and longitudinal section of No. 2 furnace.

Before describing present reverberatory furnace operation, a brief description of the coal plant will be given and some mention of the roasters and converters will be made, with particular reference to those features which are of importance to the reverberatory furnaces.

Coal Plant

The original coal plant, which was designed for the storage system, was converted to the unit system in 1929 after serious trouble with fires and explosions.[3] Further changes in equipment have since been made and the present arrangement of the plant is shown in Figs. 1 to 3. Raw coal is drawn from storage and fed to one of two rotary driers and then elevated to surge bins above the pulverizers. There are three pulverizing units for the reverberatory furnaces, one for each furnace and a third which can be used as a spare on either furnace. Each unit consists of a feeder, a ball mill in closed circuit with a classifier, and a fan which delivers the pulverized coal to the furnace. There are also two small pulverizing units for the anode furnaces.

The feeders are Hardinge Constant Weight feeders driven by variable speed direct current motors. The speed regulating rheostat for each feeder, together with an indicating tachometer calibrated in "tons of coal per day," is located at the furnaces. With this arrangement the rate of firing can be directly observed and controlled by the furnace operator. This system gives accurate control and regulation of the firing rate on the furnaces and is an important factor in fuel economy.

The pulverizers are Hardinge conical mills, the mill on No. 1 furnace being 9 ft x 60 in. in size, the one on No. 2 furnace being 8 ft x 60 in., while the mill on the spare unit is 7 ft x 60 in. The 8 ft x 60 in. mill went into service in 1940 when the firing rate was about 160 tons of coal a day, while the 9 ft x 60 in. mill was installed in 1944, in anticipation of going to a firing rate of 200 tons of coal a day on one furnace. Both these mills are larger than is required for the current tonnage of coal and are operated with a reduced ball load. In general, ball mill service has been excellent, the ball consumption is low, and the mill liners appear to have an indefinite life. Perhaps the chief objection to ball mills for coal is that the power consumption may be higher than with other types of pulverizers. However for service on unit systems with reverberatory smelting furnaces, the freedom from outage with ball mills and their ability to regularly deliver coal pulverized to the required fineness are important advantages.

A fineness of at least 90 pct −200 mesh is required for the pulverized coal and the classifier is adjusted to produce coal of this fineness. A typical screen analysis of the pulverized coal is as follows: +100 mesh, 0.7 pct; −100 mesh +200 mesh, 8.4 pct; −200 mesh, 90.9 pct.

The fan on each pulverizing unit delivers the coal and air mixture from the classifier into a system of piping which supplies the four furnace burners. The coal plant is some distance from the furnace building, the coal delivery pipes being about 170 ft long for No. 1 furnace and about 240 ft long for No. 2 furnace.

As far as the reverberatory furnaces are concerned, the three important features of coal plant operation are: 1—drying the coal to a moisture content of from 1 to 1½ pct, 2—accurate control over the rate at which coal is fed to the grinding units, and 3—pulverizing the coal to at least 90 pct −200 mesh.

Roasters

The average roaster feed for the period January to March 1953 is given in Table I, which shows that the principal constituents are direct smelting ore,

Noranda concentrates, and custom concentrates. A notable feature is the high gold content of these materials. The fluxing ore is purchased siliceous gold ore. There are ten multiple hearth Wedge roasters of which eight are regularly used.

It has already been noted that hot calcine, uniform in character and composition, is an important factor is obtaining high furnace tonnages and good fuel ratios. Previous papers[3-4] have described the changes that were made to the roasters to yield hotter calcine and, equally important, how the roaster Cottrell dust and the roaster flue dust were returned to the roasters to be mixed and heated with the calcine. In effect the roasters were altered so that they would operate at a higher temperature and this additional heat was used to bring the dust up to the temperature of the calcine. All the difficulties and troubles which may result from the separate charging of fine dust to the reverberatory furnaces are thus avoided.

Since 1950 an improved method of returning the roaster Cottrell dust to the roasters has been in use, replacing the original system developed in 1937, which consisted of a number of "blow tanks" using high pressure air. In 1950 a new and larger roaster Cottrell plant was completed and provision was made for returning the collected dust by means of a Fuller pump to a bin centrally located above the roasters, from which the dust is distributed among the roasters by two Fuller-Huron "Air Slides." This method of handling Cottrell dust is an improvement over the old system in that the use of expensive high pressure air is eliminated; added advantages are that it avoids the cooling effect that resulted from blowing the dust into the roasters with air, and that the dust can be more uniformly distributed among the roasters. The calcine from the furnaces is now hotter and more uniform than ever before, and this has been a factor in the improvement in fuel ratio which has been made in recent years.

The roasters are operated to give the hottest possible calcine consistent with making the sulphur elimination required to give the desired matte fall in the reverberatory furnaces, the usual calcine temperature at the roaster discharge being about 1200°F. Ordinarily no fuel is required in the roasters except when a roaster is started after a shutdown for repairs.

Converters

Only brief mention need be made of converter operation. There are five converters in all, two 12 x30 ft shells which are the original converters, two 13x30 ft shells which were added in 1929, and one 13x28 ft shell which went into service in 1940. At present only three converters are in operation at one time, service being rotated among the three 13 ft shells and one 12 ft shell. There are three 40 ton cranes, of which two are in regular use, and the ladles for matte and converter slag are of nominal 200 cu ft capacity which deliver about 17 tons of matte and 13½ tons of slag. There are two anode furnaces, only one of which is in regular service. Copper production is at the rate of about 6300 tons a month and is shipped in the form of anodes to Canadian Copper Refiners at Montreal East.

Present Furnace Operation

In the years 1928 to 1943 there were no restrictions imposed on smelter tonnage and the capacity of the reverberatory furnaces could be developed to the full, limited only by the size of the roasting plant. During the period 1944 to 1949 although the smelter tonnage was sharply curtailed, the one furnace that was in operation was maintained at maximum capacity. Since two-furnace operation was resumed in 1949, the quantity of ore and concentrates available is only sufficient to maintain a tonnage of about 1400 tons of solid charge per furnace day. In current operation the emphasis is therefore not on tonnage, as in the past, but on improvements in practice to reduce furnace costs and losses.

Furnace design is illustrated in Figs. 4 to 6, which show No. 2 furnace in both plan and section. An important feature is the gradation in the cross-sectional area of the furnace along its length, with the object of efficient combustion of fuel and utilization of heat within the furnace. The maximum area of 160 sq ft begins at a point 6 ft from the firing wall and extends 30 ft along the furnace, while from there on the area is gradually reduced to 115 sq ft in the section adjacent to the uptake. These areas are net areas based on the normal slag level in the furnace and allowing for the space taken up by the amount of calcine and fettling material that is normally on the side walls. The net area of the outlet flue is about 90 sq ft, after allowing for the normal accumulation of ash and clinker on the walls and floor of the flue. The constriction near the uptake end is a result of its being impracticable to widen the furnaces for their entire length and is perhaps not a desirable feature. However this reduction in area is not as great as might appear because in the narrow part of the furnace the only material charged is coarse siliceous ore which, with its steep angle of repose, does not take up as much room as does calcine.

The sections through the furnace shown in Figs. 5 and 6 illustrate the flexibility of suspended construction for giving any desired roof contour. Specially shaped roof tile is used in the shoulders of the furnace roof and also in the slopes of the uptake roof. This special tile is preferred to the standard shape for sloping sections because with it the roof can be kept clean more easily and also because the hot face of the shoulder or slope is less liable to damage from spalling. It will be noted that suspended blocks of basic refractory, locally termed "side-wall cans," are used in the upper part of the side walls and of the firing wall. The replacement of brickwork in these parts of the furnace was a minor problem before the use of these suspended side-wall cans was developed.

Firing Practice

Since two-furnace operation was resumed in 1949, the rate of firing on the furnaces has been varied from 120 to 140 tons of coal a day. At the present time it is being maintained at about 125 tons a day, which experience has shown to be close to the minimum tonnage for efficient operation with the present size of furnace. The coal used is bituminous coal from the Sydney district in Nova Scotia and a typical analysis is as follows:

Moisture content as-received	3 to 5 pct
Proximate analysis, dry basis:	
Volatile matter	36.5 pct
Fixed carbon	55.9 pct
Ash	7.6 pct
Sulphur	2.1 pct
Btu per lb	13,970

The current price for coal is $12.71 a ton f.o.b. Noranda and the cost of handling and pulverizing is

Table II. Reverberatory Furnace Data

Period	Tons per Furnace Day: Calcine	Other Charge	Total Solid Charge	Coal Burned	Fuel Ratio, Pct	Million Btu per Ton of Solid Charge	Lost Time for Brick Repairs in Furnace Days
1934	1144	82	1226	135	11.05	3.04	12.8
1941	1484	40	1524	153	10.06	2.71	0.2
1945	1990	56	2052	212	10.33	2.73	0.0
1951	1318	20	1338	130	9.72	2.64	0.0
January to March 1953	1381	37	1418	125	8.82	2.41	0.0

about $1.00 a ton. The coal as received contains 26.8 million Btu per ton so that the cost of pulverized coal delivered to the furnaces is $0.51 per million Btu. With this high fuel cost, efficiency and economy in fuel consumption are of the utmost importance. This is particularly true because, for reasons which are given later, the value of the credit for waste heat steam is small compared with the similar credit at many other smelting plants.

There are four coal burners on each furnace and the arrangement of one of the burners and the secondary air supply are shown in Fig. 7. The burner tips, made of cast iron, are of "fish-tail" design and are connected to a 9 in. lateral, one leg of which joins the coal piping while the other leg serves as an inlet for the secondary air. The secondary air pipe in the burner tip is a 4 in. pipe reduced to a nozzle with a diameter of 3¼ in. Secondary air is supplied by a centrifugal blower, the driving side of which is a pass-out turbine taking steam at 175 psi from the high pressure steam main and exhausting at 40 psi into the low pressure main which supplies steam for plant heating and process work. The turbine, which has variable speed control, is direct-connected to a two-stage blower equipped with diffuser vanes. This arrangement makes possible a wide range in both volume and pressure, sufficient to take care of the air required for one furnace at low tonnage or the air required for two furnaces at high tonnage. The air inlet to the blower is equipped with steam heaters which maintain a constant inlet temperature of 100°F so that for any given pressure setting the blower delivers a constant weight of air.

At present the secondary air supply to the two furnaces is about 17,000 cfm measured at 100°F and 28.8 in. Hg and the pressure at the blower discharge is 3.5 psi. The power equivalent of the steam required by the turbine is about 275 kw and it might be argued that this is expensive secondary air. However experience at Noranda has shown that secondary air under pressure is necessary to obtain high furnace tonnage and good fuel ratios when burning pulverized coal.

A good deal of experimenting has been done with secondary air nozzles and burner tips, most of it on an empirical basis, from which one or two principles have been established. Apparently the important effect of the secondary air is the turbulence it gives to the coal and air mixture, which produces rapid combustion and high flame temperature. To obtain maximum turbulence, it seems that volume is necessary as well as pressure; for example, it has been found that 8500 cfm at 3½ psi is more effective than 5000 cfm at 6 psi. Experimentation has also shown that the size of the burner tip is important, a small tip giving comparatively slow ignition while with a larger tip ignition takes place more rapidly. For the tonnage of coal now being burned, a tip that meas-

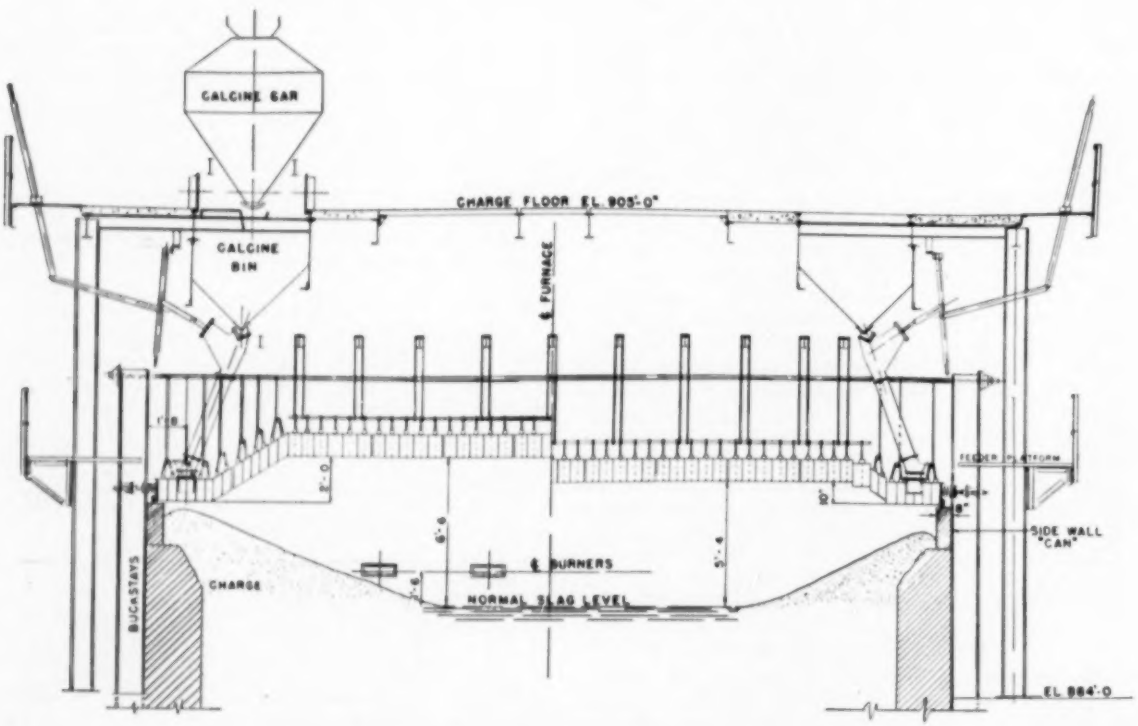

Fig. 5—Half section through No. 2 furnace at *A-A* and *B-B*, Fig. 4.

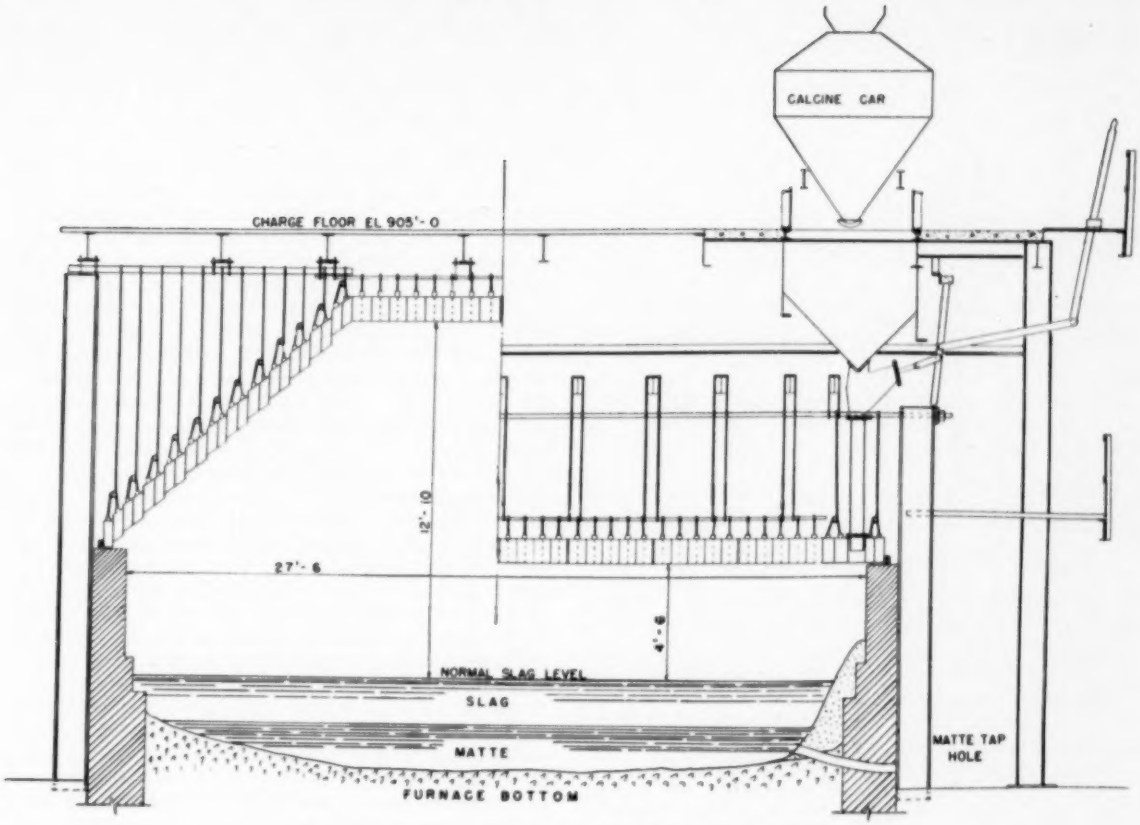

Fig. 6—Half section through No. 2 furnace at C-C and D-D, Fig. 4.

ures 13x4 in. at the discharge is giving very satisfactory results.

The quantity of air required for the combustion of 125 tons of coal a day and to give a slight excess of oxygen is 27,000 cfm measured at 100°F and 28.8 in. Hg. Of this, 9500 cfm is supplied as primary air with the coal and 8500 cfm as secondary air, which means that 9000 cfm, or one-third of the total combustion air, comes into the furnaces as induced air or leakage. This seems high and perhaps future improvement in furnace firing lies in finding ways of reducing this quantity of air and supplying it under pressure.

As a guide in firing control, regular Orsat analyses are made on gas samples taken with a water-cooled sample tube through the center of the furnace roof at a point about 13 ft from the uptake. A typical gas analysis is as follows: $CO_2 + SO_2$, 18.3 pct; O_2, 0.4 pct; CO, 0.0 pct. These samples are taken at a fixed point and are therefore not necessarily representative of the gas analysis over the whole area at that section of the furnace. Nevertheless, experience at Noranda has shown that these gas samples and analyses are of the utmost value in combustion control.

At the present time the practice is to set the firing rate at a figure close to 125 tons of coal a day and to leave it unchanged, adjusting the secondary air when necessary to give the correct gas analysis and altering the tonnage of feed to the roasters should the smelting rate vary. It has been found that from the point of view of fuel economy this practice is better than attempting to maintain a constant furnace tonnage, which requires changing the firing rate if the rate of smelting should change.

With a uniform firing rate and a constant weight of secondary air, the two variables in combustion control are the primary air supply and the air that enters the furnace as induced air through the burner openings and as leakage through charge openings or elsewhere. The weight of the primary air is affected by the temperature in the coal plant, which varies between day and night and also with the seasons of the year, but ordinarily the effect of these changes is small. However, changes in furnace draft have a considerable effect on induced air and leakage, and therefore close regulation and control of furnace draft are of prime importance. Furnace

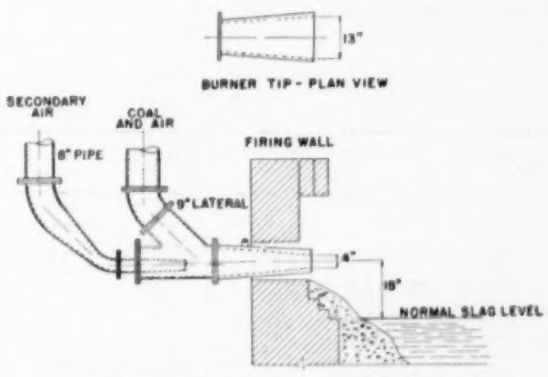

Fig. 7—Burner and secondary air arrangement.

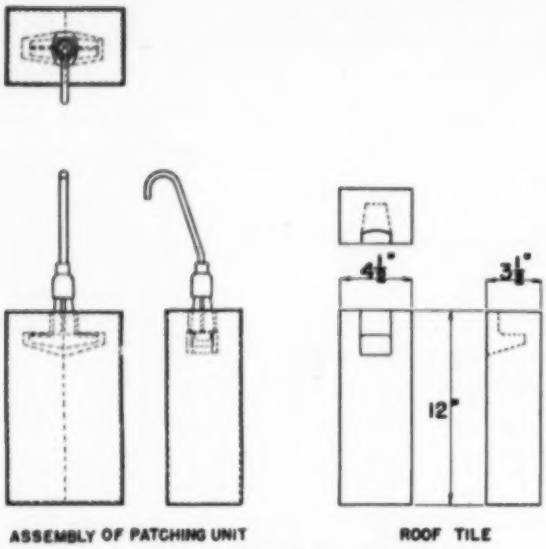

Fig. 8—Roof tile and assembly of patching unit.

draft, measured at the same point in the furnace roof as the gas samples are taken, is maintained at minus 0.03 in. of water by adjusting the boiler outlet dampers or the by-pass flue damper. In addition to the usual indicating draft gage, each furnace has a draft recorder and these have been found to be of great value in maintaining uniform draft conditions. The principle of having a graded area along the length of the furnace has already been mentioned. One important advantage of this design is that it gives a well balanced draft condition throughout the furnace length. This is shown by the fact that, when the uptake end of the furnace is under slight suction, the zone of maximum temperature and smelting at the firing end is either neutral or under slight pressure.

Charging Practice

It is essential that there be a wide clear channel between the "toes" of the two charge banks in the furnace to allow free flow of matte and slag to the skimming end of the furnace. Bridging of this channel may occur if both sides of the furnace are heavily charged and the charge banks should slide. To prevent this, frequent small charges are made on alternate sides of the furnace, the present practice being to charge every 30 min, one side on the hour and the other on the half hour. Frequent charging has the added advantage that a more uniform combustion area is maintained in the furnace. The section through the furnace shown in Fig. 5 represents a typical condition of the charge banks in the smelting zone, with one side fully charged and the other partially smelted. Wide furnaces, such as those at Noranda, are a necessity for obtaining high tonnage with roasted charge on a side fed furnace.

Calcine is trammed from bins beneath the roasters in cars of 10 ton capacity drawn by battery locomotives, there being one car and motor for each furnace. The car is emptied into the furnace bins and fed directly to the furnace, the slide gates on a selected group of feed pipes having been previously opened. A charge consists of two or three cars of calcine for which the charging time required is from 10 to 15 min. Inspection ports are provided in the firing wall on each side of the furnace through which the size and condition of the charge bank can be observed for some distance down the furnace. There is also a peep hole in each charge pipe through which the charge bank can be seen. These arrangements for inspection make possible close supervision of charging and charge distribution.

Coarse siliceous ore is used for fettling the firing wall and also the side walls for some 20 ft adjacent to the uptake, no calcine being charged in this latter zone because it is too close to the slag tap hole. A small quantity of reverts is available and is used should the bank get particularly low at any point in the furnace. Dust recovered in the reverberatory furnace and converter Cottrell plants is brought to the furnace in cars of 3 ton capacity and charged in the same way as calcine. The total of fettling, reverts, and dust forms only a small part of the furnace tonnage, about 97 pct of the total solid charge to the furnace being calcine.

Converter slag is poured into the furnaces through a launder in the center of the firing wall, this launder being at about the same level as the coal burners. Because the matte is low grade, the quantity of converter slag is considerable, amounting to approximately 600 tons per furnace day.

Matte and Slag Handling

The depth of matte and slag in the furnace is measured three times a shift, at a point near the gas sampling station, and changes in the depth of matte are used as a guide in regulating the sulphur elimination in the roasters. A typical measurement is 40 in. of total liquid, with 20 in. of matte and 20 in. of slag. There are two matte tap holes for each furnace, located as shown in Fig. 4, and the matte is tapped through a short launder into a ladle which sits on a transfer car in the matte tunnel between the two furnaces. When the ladle has been filled, the car is drawn to the converter aisle by means of a car pull.

The use of a matte tunnel is not general practice

Table III. Reverberatory Furnace Slag and Matte Analyses

Year	Au, Oz per Ton	Ag, Oz per Ton	Cu, Pct	SiO_2, Pct	Fe, Pct	Al_2O_3, Pct	S, Pct	CaO, Pct	MgO, Pct
Slag Analyses									
1934	0.0067	0.037	0.27	38.0	35.3	8.6	0.9	1.6	1.0
1941	0.0045	0.053	0.33	38.1	36.8	6.6	1.1	1.2	1.1
1945	0.0044	0.060	0.34	37.3	35.8	7.4	1.5	1.6	1.5
1951	0.0046	0.078	0.32	38.6	35.9	6.6	1.5	1.5	1.9
January to March 1953	0.0045	0.080	0.31	38.5	35.6	6.2	1.3	2.1	0.7
Matte Analyses									
1934	1.30	2.9	20.0		47.5		22.5		
1941	0.80	4.3	22.4		45.0		23.7		
1945	0.70	4.3	21.8		44.7		23.1		
1951	0.88	6.9	20.9		45.0		23.0		
January to March 1953	0.89	6.3	20.4		45.0		23.9		

Table IV. Furnace Repair Costs

Tons of Solid Charge per Year	Roof Brick Used per Year, Lb	Roof Brick per Ton of Charge, Lb	Repair Labor, Man-Hours per Year	Repair Cost per Year				Repair Cost per Ton of Solid Charge
				Total Roof Material	Total Other Material	Labor	Repair Cost	
984,000	787,000	0.80	16,800	$85,400	$5,400	$21,500	$112,300	$0.114

at copper smelters and perhaps deserves mention. Without a tunnel, or some similar arrangement, the matte must be tapped near the firing end of the furnace, and it is inevitable that the skimming end of a furnace tapped in this way will fill with magnetite to a degree that makes the skimming of clean slag difficult if not impossible. The furnace must then be shut down to dig out the bottom. When a tunnel is used, the tap holes can be located near the skimming end of the furnace, which can then serve its true function: to act as a settling basin and a storage reservoir for matte and slag. The regular flow of matte to the tap holes helps prevent the accumulation of magnetite at the skimming end of the furnace and thus makes possible longer furnace campaigns. Apart from the question of first cost, the only disadvantage of a tunnel is that it may add to the trouble that can be caused by a runaway taphole. Based on Noranda experience, this risk is not a serious drawback to the use of a matte tunnel.

Furnace slag is not skimmed from the surface of the bath but is tapped through a slot in the front wall of the furnace at a level about half way up the layer of slag shown in Fig 6. Ordinarily the slag is tapped at a fixed level at the bottom of the slot, the tap hole being raised only when the depth of matte in the furnace is unusually great. There is little trouble with "floaters," but occasionally there is some difficulty due to "silica mush" which may accumulate in the furnace and float to the slag hole on the bath. Generally this condition results from an unexpected change in roaster feed which may temporarily give a charge containing an excessive amount of silica.

Two four-pot slag trains are used, the pots having a nominal capacity of 200 cu ft and delivering about 16 tons of slag each. The slag trains are drawn to the dump by trolley locomotives and the molten slag is granulated to be used in the mine for backfill. With this method of slag disposal, dump sampling is impracticable and regular slag samples taken at the furnace are used for control purposes.

Furnace Data

Data on furnace tonnage, fuel ratio, and lost time for repairs are given in Table II for a representative year in each of the four different periods of furnace operation between 1928 and the present time. The table also gives similar figures for a three month period in 1953 which represents the best furnace performance that has been obtained at the current rate of operation. Tonnages are actual weights of solid charge to the furnaces, and the coal consumption and fuel ratios are based on the weights of raw coal received and the Btu content of the coal for the period concerned. In recent months the fuel ratio on the furnaces has been the best in the history of the smelter, as is shown by the figures for January to March 1953. There is no single factor which had brought this about; it has come as the result of a number of small improvements in the roasters and in furnace operation and firing control.

Matte and slag analyses are given in Table III for the same representative periods as in Table II. The use of limerock as a flux is not practicable at Noranda, and the furnace slag therefore is essentially a straight silica-iron slag containing the alumina and the small amounts of lime and magnesia that are naturally present in the charge. Slag losses at Noranda are of interest because of the high gold and the low copper content of the material being smelted. Data on slag losses were presented in some detail in both tabular and graphical form in a previous paper.[4]

Furnace Repairs

The furnace roofs are maintained by "hot patching," that is, the regular replacement of sections of the roof as the brick burns out, without shutting the fire off or affecting normal furnace operation. The patching "unit," shown in Fig. 8, consists of two roof tiles supported by a hanger and enclosed in a casing of light sheet metal, the assembly weighing about 40 lb. Standard shape 12 in. tile is used in the main part of the roof and special shoulder tile in the sloping sections, while some 9 in. and a few 15 in. tiles are also required. Unburned, chemically bonded magnesite brick containing about 20 pct chrome is used. Patching of the center of the roof is done from the charge floor level while the shoulders and the charge hole areas are patched from the feeder's platform. Roof tiles are replaced when they have been burned out to a thickness of 2 in. or less and a single patch usually covers an area of about 4 or 5 ft square. The old bricks are knocked into the furnace a few at a time and new tiles are hung in their place, so that at no time is there any large hole in the roof, and except for increasing the draft slightly, there is no change in the regular operation of the furnace when the roof is being patched. By using proper care in patching and with the natural expansion of the brick, there is no difficulty in maintaining a tight roof. The use of side-wall cans for the upper part of the furnace walls has already been mentioned. The "can" is a light metal container enclosing a block of tamped basic refractory made from grain magnesite and chrome-base cement together with some sodium silicate, the blocks being suspended from supports carried on the buckstays. Other than the replacement of roof tile and side-wall cans, there is little repair work required on the furnace brickwork.

In Table IV figures are given for the annual repair cost for brickwork on the furnaces, based on the actual cost figures for the past two years. The biggest single item is, of course, roof tile, which amounts to 0.80 lb of brick per ton of solid charge. Expressed in other terms, the quantity of roof tile used means the replacement of about 75 pct of the area of the furnace roofs each year. The labor required for furnace repairs is given in man hours and includes the labor for handling brick and other refractories to and from storage. The total cost of all brickwork repairs, including labor, amounts to $0.114 per ton of solid charge. These cost figures are

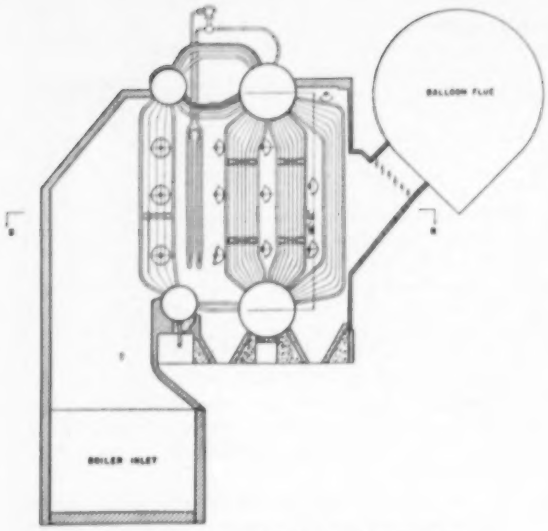

Fig. 9—Section through boiler at *A-A*, Fig. 10.

based on a relatively short period of operation, but nevertheless it is believed that, with the present roof and furnace construction and at the current tonnage, the furnaces can be maintained for a period of many years for a total repair cost of the order of $0.12 per ton.

Waste Heat Boilers

Waste heat boilers to generate steam for power were not provided when the smelter was originally built because it was believed that, with cheap hydroelectric power and high cost fuel, the waste furnace gases should be used to preheat combustion air and thus reduce fuel consumption. A specially designed preheater, built to take gases from No. 1 furnace, was therefore included in the original smelter design. The story of the failure of this preheater has already been told[3] and need not be repeated here except to say that the chief troubles were the high temperature and the heavy dust loading of the furnace gases.

In order to supply heating steam, a 750 hp boiler was provided on No. 2 furnace in 1929 and a similar boiler was added to No. 1 furnace in 1933. At that time the preheater was still under trial and no great thought had yet been given to developing power from waste heat. As a result the boilers were designed for the comparatively low pressure and temperature of 175 psi and 525°F, and these design conditions have been maintained for subsequent boilers. After use of the preheater had been abandoned, a 1000 hp boiler was added to No. 1 furnace in 1935 and finally a boiler of the same size went into service on No. 2 furnace late in 1939, so that each furnace was then equipped with one 750 hp and one 1000 hp boiler. Two turbogenerator sets were provided for the production of power from waste heat steam, the first unit in 1935 and the second in 1940.

The first three boilers were four-drum Stirling-type boilers while the fourth was of special design arranged for auxiliary firing. The chief difficulties with these boilers were the rapid erosion of tubes in the first bank, which caused frequent shutdowns, and the fact that it was difficult to keep the boilers clean even though soot blowers were used supplemented by regular hand lancing. As a result steam production from the boilers was comparatively low and costs were high.

In 1949 it became evident that the original boilers would soon have to be replaced because of age and obsolescence and it was decided that the new boilers should be patterned after the design of some of the recent waste heat boiler installations at copper smelters in the United States. The arrangement of one of these new boilers is shown in Figs. 9 and 10, the important features of design being the absence of baffles, horizontal gas flow at low velocity, improved soot blowing, and minimum height to avoid stack effect. Because the inlet gas temperature is comparatively low, water walls are not required in the boiler inlet chamber and in any case they would not be practicable because of possible acid condensation and corrosion with the low steam temperature. The first bank consists of widely spaced 3 in. tubes, 6 gage, fitted into large drums for ease of replacement, while the convection bank is made up of closely spaced 2 in. tubes. Twenty-four "Air Puff" soot blowers are provided, twelve on each side of the boiler, using air at 250 psi, and the entire boiler setting is of suspended construction. Total heating surface is 10,800 sq ft and the maximum rating of the boiler is 30,000 lb of steam an hour at 175 psi and 525°F.

The arrangement of the boilers with respect to the furnace is shown in Figs. 11 and 12, from which it will be seen that the two boilers are located on either side of and above the outlet flue from the fur-

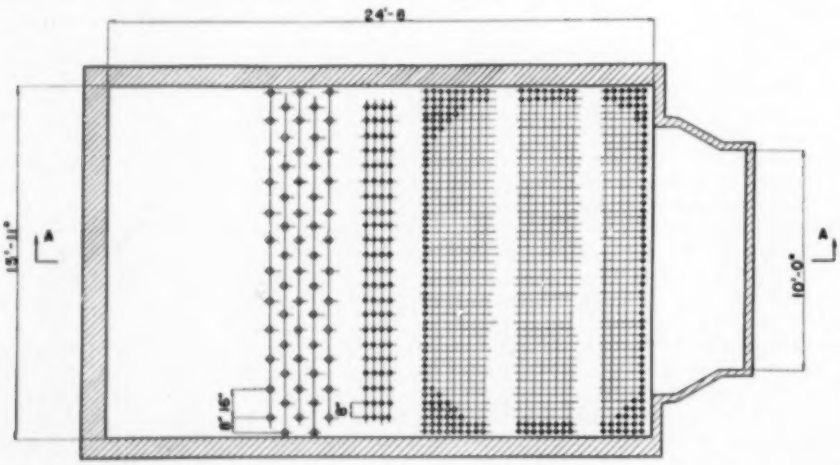

Fig. 10—Section through boiler at *B-B*, Fig. 9.

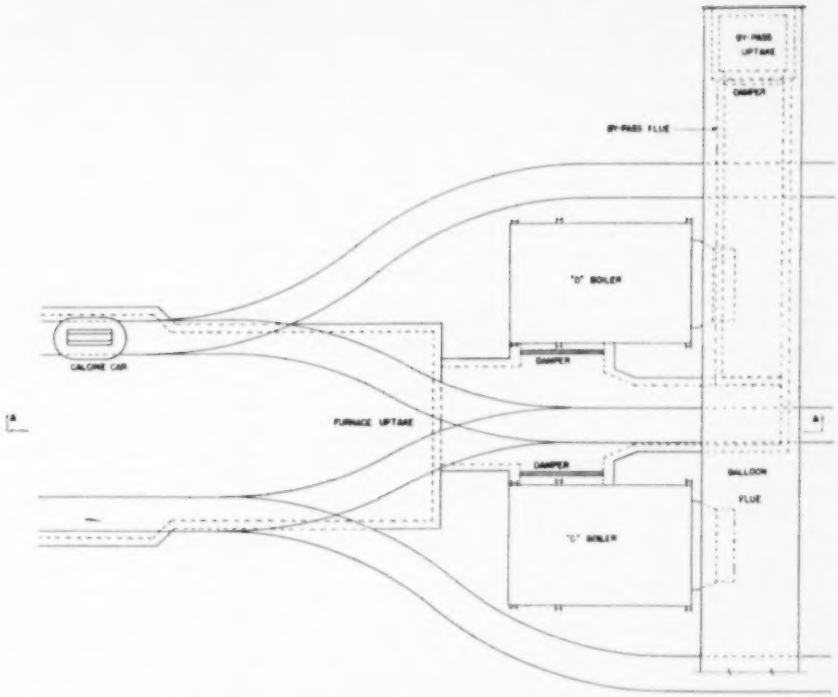

Fig. 11—Arrangement of boilers and flue system on No. 2 furnace.

nace. This boiler arrangement does not lend itself to efficient waste heat steam production because of the long indirect passage for gases from the furnace to the boilers, but it is difficult to improve with the existing layout of the furnace, building steel, flue system, and calcine tracks. Each boiler is provided with a shut-off damper and when one boiler is down, part of the furnace gases go through a by-pass flue which is equipped with a regulating damper.

The first of the new boilers went into service in July 1951 and the second in June 1952, while a third unit was scheduled for 1953. Experience to date has shown that this type of boiler will give very satisfactory service for conditions at Noranda and that it is a marked improvement over the old boilers. Perhaps the chief merit is that the boiler can be kept clean by the use of the soot blowers alone, no hand lancing whatever being required. Because the boiler is always clean, steam production is more uniform and furnace draft is less subject to variation, while with lower gas velocities in the boiler it is evident that tube life will be much longer than with the old type of boiler. With two of these new boilers on a furnace, it is expected that steam production will be about 45,000 lb of steam an hour when burning 125 tons of coal a day, which represents about 35 pct of the heat content of the fuel burned in the furnace. It is estimated that when all the new type boilers are in service, the cost of producing waste heat steam, including all the costs of operating and maintaining the boilers but with no allowance for capital charges, will be about $0.10 per thousand pounds of steam.

It might be of interest to outline the economics of waste heat steam production at Noranda. The power generated from waste heat steam is used to reduce the quantity of hydroelectric power purchased so that the value of waste heat steam can be set by the value of the power it will generate. On this basis, for the steam conditions and the power cost at Noranda, the gross value of steam is $0.30 per thousand pounds of steam, and since the boiler costs amount to $0.10 per thousand pounds, the net value of steam as a credit to furnace operation is $0.20 per thousand pounds. A calculation will show that with the figures that have been given for furnace fuel

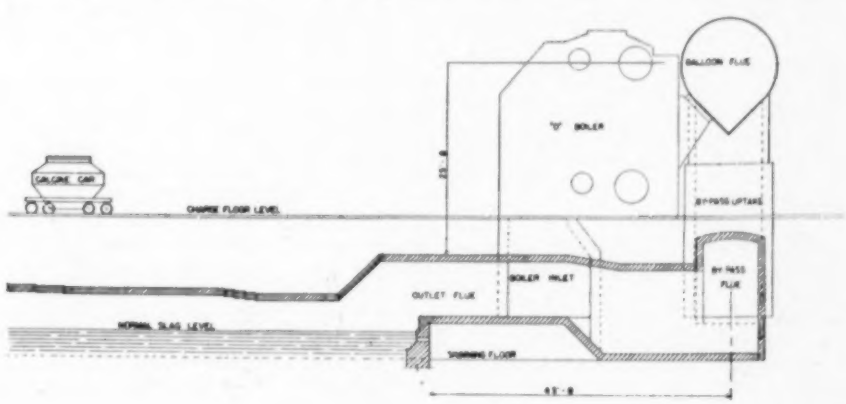

Fig. 12—Section through No. 2 furnace flue system at A-A, Fig. 11.

consumption, coal cost, and steam production and value, the gross credit for waste heat steam amounts to about 20 pct of the furnace fuel cost while the net credit is 13 pct. These are low figures compared with those smelting plants where fuel is cheap and where waste heat steam replaces steam generated in direct-fired boilers.

Furnace Cottrell Plant

When two-furnace operation was resumed in 1949, it was decided to install additional Cottrell equipment to reduce stack losses, because of the increased gold and copper input to the smelter, coupled with a higher price for copper. Accordingly a new and larger roaster Cottrell plant was built and the old roaster is now used for the treatment of the reverberatory furnace gases. This program had the twofold object of reducing the roaster losses and effecting a dust recovery from the furnace gases, which had previously been going to the stack without treatment. The new roaster Cottrell went into operation in 1950 and the Cottrell plant for the furnace gases has been in use since early in 1951. Results have been very satisfactory and the combined stack loss from the roasters and reverberatory furnaces has been reduced to a very low figure.

Information on the operation of the furnace Cottrell plant and of the dust recovery that is being made might be of interest. Because of the boiler replacement program, there have been only a few periods during which four boilers have been in operation to give gas volumes and temperatures that can be considered normal. It might also be noted that the present furnace flue system is a complicated one with the result that dilution of the furnace gases is excessive. When the last of the new boilers goes into service, it will be possible to simplify the outlet flue system behind the boilers and it is expected that this change will reduce the gas volume to the Cottrell plant. Despite these abnormal conditions, the Cottrell is making an excellent recovery of the dust in the furnace gases.

The Cottrell plant is of the rod-curtain type and consists of six units in parallel, each unit being fifteen "ducts" wide and having three sections in series. Inlet and outlet dampers are provided on each unit and rapping of the electrode systems for dust removal is by means of pneumatic hammers. The recovered dust falls into hoppers and is drawn off into cars to be charged to the furnaces. Although there is considerable zinc and some lead in the furnace gases, Cottrell operation is generally smooth and excellent collection efficiencies are obtained in the periods of normal gas volume. When one boiler is out of service, the gas volume and temperature are higher which results in somewhat lower efficiencies. The collected dust is weighed and sampled and the gases in the outlet flue from the Cottrell to the stack also are sampled regularly to determine the dust loss, using a method of continuous sampling developed at Noranda. Some system of regular measurement of the loss from a Cottrell is essential for controlling Cottrell operation and maintaining high collection efficiency.

The Cottrell collection efficiencies on dust and metals for September 1952, a typical month with four boilers in operation, together with the gas volume and temperature, are as follows: dust, 92.0 pct; gold, 94.3 pct; silver, 91.1 pct; copper, 93.9 pct; gas volume, 372,000 cfm at 340°F and 28.5 in. Hg.

The weight and metal content of the Cottrell dust collected for this month are given in Table V, together with the Cottrell loss and other figures on dust loading. The metal content of the Cottrell recovery varies from month to month depending on the grade of the furnace feed. Based on the collection figures for 1951 and 1952, the metal content of the dust recovered in the Cottrell per year amounts to 1900 ounces of gold, 40,000 ounces of silver, and 250 tons of copper, with a gross value of about $250,000 at current metal prices.

The total dust loading of the reverberatory furnace gases is perhaps of some interest. The additional information required to obtain this figure is the amount of dust collected at various points in the flue system ahead of the Cottrell, made up of daily cleanings from the furnace outlet flues and boiler inlets, dust that collects in the boilers, and dust that is recovered in the periodical cleaning of the flue from the boilers to the Cottrell. These products are not ordinarily weighed and sampled but an accurate estimate was specially prepared covering a representative period of current operation. In Table V are given the tonnage and metal content of the recovery ahead of the Cottrell, of the dust collected in the Cottrell, and of the Cottrell loss, all for the month of September 1952. The sum of these represents the dust loading of the gases at the furnace outlets, and the weight and metal content of this loading is given in Table V, and is also shown expressed as a percentage of the weight and metal content of the solid charge to the furnaces. The dust is much lower in copper than the furnace charge, this being the result of dilution with coal ash. The figures show that dusting from the furnace charge is comparatively low; this is undoubtedly due to the fact that only one-third of the roaster charge is concentrates, the balance being crushed material, that is, direct smelting ore and siliceous flux. The gold and silver content of the dust indicates that there is some volatilization of the precious metals in the furnaces.

Canadian and American Practice

It happens that at the three Canadian smelters which are using reverberatory furnaces, Copper Cliff, Flin Flon, and Noranda, the metallurgical and economic conditions which govern furnace practice are quite similar. First, the material to be smelted is low grade and therefore requires roasting, the one exception to this being Copper Cliff where there is some direct smelting of copper concentrates. Second, fuel is expensive and the value of waste heat steam is relatively low so that efficient utilization of heat within the furnace is important. Third, spare furnaces are not available and with large tonnages of low grade material to be smelted, methods of furnace construction and maintenance are required which will give long campaigns at high tonnage rates.

At Copper Cliff there are seven furnaces for the smelting of roasted nickel-copper concentrates.[5] These furnaces are side fed, pulverized coal is the fuel, suspended roofs are used, and maximum furnace tonnages are required. As at Noranda it was found necessary to widen the furnaces to obtain high tonnages. Only a few of the furnaces at Copper Cliff are equipped with boilers, and waste heat steam is generated for plant heating and process work only. In addition to the seven furnaces on calcine smelting, there are two furnaces for the direct smelting of copper concentrates. It is of interest to note that the first successful use of pulverized coal firing together with side charging was on a

Table V. Dust Loading of Furnace Gases, September 1952

Material	Tons	Analysis					Content				
		Au, Oz per Ton	Ag, Oz per Ton	Cu, Pct	Zn, Pct	Pb, Pct	Au, Oz	Ag, Oz	Cu, Tons	Zn, Tons	Pb, Tons
Flue and boiler cleanings	145	0.21	2.4	5.4	3.4	0.7	30	340	7.8	4.9	1.0
Cottrell dust recovered	516	0.32	5.4	3.9	10.1	1.8	165	2,770	20.1	52.1	9.3
Cottrell loss	45	0.22	5.9	2.8	14.4	2.6	10	270	1.3	6.5	1.2
Total dust loading	705	0.29	4.8	4.1	9.0	1.6	205	3,380	29.2	63.5	11.5
Solid charge to furnaces	82,250	0.37	2.7	8.1	1.1	0.1	30,600	220,000	6,650	870	80

Loading as Percent of Solid Charge

Weight	Metal Content				
	Au	Ag	Cu	Zn	Pb
0.86	0.67	1.54	0.44	7.3	14.4

furnace at Copper Cliff in 1911, and that these two features of furnace practice are still in use at Canadian smelters.

The smelter at Flin Flon, also a roaster-reverberatory furnace plant, holds perhaps a unique record in that the one reverberatory furnace has been operating regularly for over twenty years without a serious break in production. The suspended basic roof was first used at Flin Flon in the early years of operation and there is no doubt that this type of roof has helped to make possible the record for continuous operation with a single furnace that has been established by this smelter. Pulverized coal is used for fuel, the furnace hes been widened to increase capacity, and the production of waste heat steam is of secondary importance because the company has its own hydroelectric power plant. Recently a zinc fuming furnace was built for the treatment of reverberatory furnace slag, and the normal smelter feed of copper concentrates was supplemented by a quantity of zinc plant residue. Thus the reverberatory smelting furnace has begun to play a part in the treatment of what has long been a "problem" by-product of the electrolytic zinc plant.

Two important features of modern practice at copper smelters in the United States are the continued trend to the direct smelting of concentrates without roasting and the widespread use of natural gas for fuel. The merits of direct smelting, first established at Cananea some twenty-five years ago, were further proved by the adoption of this method at Miami, McGill, and Douglas. Since then the three new smelters that have been built, Hurley, Morenci, and Ajo, were all designed for direct smelting. There are, of course, a number of roaster-reverberatory plants still in operation where special local and metallurgical conditions, as in Canada, make this practice preferable to direct smelting. At those American smelters which are still "hot charging," the use of Wagstaff guns for feeding the furnaces is now general. This is in contrast to the practice at Canadian smelters where, with wide furnaces and favorable charge conditions, side charging is still the preferred method of feeding the furnaces

Although natural gas as a fuel for reverberatory furnaces is less efficient than fuel oil or pulverized coal, nevertheless it is used wherever it is available because of its cheapness and convenience. The cost of fuel at copper smelters in the United States is generally much lower than at Canadian plants. Another point of contrast between conditions at Canadian and American smelters is in the importance of waste heat steam production. It has been shown that at Noranda steam is of relatively low value and this is true to perhaps an even greater degree at Copper Cliff and Flin Flon. At most of the large copper mines in the United States, power must be generated from steam, and under these conditions the value of the waste heat steam produced in the smelter is equivalent to the cost of the fuel required to produce that same amount of steam in a direct-fired boiler. As a result the waste heat boiler installations at most American smelters are an important part of the power generating plant and the credit for waste heat steam means a considerable reduction in the furnace fuel cost. This is particularly true with direct smelting furnaces, where waste heat steam production is high and where the gross credit for steam usually amounts to from 50 to 55 pct of the furnace fuel consumption. In recent years new principles of waste heat boiler design have been developed at several American smelters and new types of boilers are now in operation which promise to further improve the general high standard of waste heat boiler practice.

In Canada "hot charged" reverberatory furnaces are operated at a much higher tonnage than is general on "hot charged" furnaces in the United States. One exception to this was in the past at Clarkdale, where a rate of 1600 tons of charge a day was reached. A comparison of furnace performance at Canadian smelters with direct smelting furnaces in the United States cannot be made on the basis of tonnage, because of the wide difference in fuel ratio with the two types of smelting. However if the comparison is made on the basis of fuel input, then it can be said that the rate on most direct smelting furnaces is comparable to 1400 tons of charge a day in terms of Canadian practice with calcine smelting. The record for tonnage on a direct smelting furnace has been set at McGill, where the average daily tonnage for May 1940 was 986 tons of charge with a fuel consumption of 223 tons,[6] a furnace performance which is comparable with 2000 tons a day on a calcine smelting furnace.

The suspended basic roof is being used on all reverberatory furnaces in Canada, in sharp contrast to practice in the United States, where sprung silica arches are still used, supplemented by "slurry patching" for roof maintenance. This fundamental difference in methods of roof construction and maintenance is perhaps not as readily explained as some of the other differences in furnace practice.

Many factors are involved which are beyond the scope of this paper to discuss and therefore no attempt will be made to assess the relative merits of the suspended roof and the sprung arch for reverberatory smelting furnaces. The important fact is that with the use of either the suspended basic roof or "slurry patching" of the sprung silica arch, smelter operators now have a means of prolonging roof life almost indefinitely. This has made possible greatly increased furnace tonnages and has at the same time resulted in lower furnace repair costs.

Summary

The development of furnace practice at Noranda has been reviewed and present operation has been described in considerable detail. Under present conditions the emphasis is no longer on maximum tonnage but on increased efficiency and in recent years the fuel ratio has been improved, modern waste heat boilers have been installed, and a considerable metal recovery has been effected by treating the furnace gases in a Cottrell plant. Canadian and American furnace practices have been compared and some explanation given for differences in principles and methods.

Acknowledgments

The history of the development of reverberatory furnace practice at Noranda would not be complete without paying tribute to Mr. W. B. Boggs, Smelter Superintendent from 1928 to 1948, whose bold pioneering was responsible for the progress of which some record has been made here. Acknowledgment is made of the permission granted by the management of Noranda Mines Limited to publish the information and data contained in this paper. The author's thanks are due to Mr. L. K. Shibley, Assistant Smelter Superintendent, and Mr. G. C. McKerrow, Metallurgist, for their assistance in the preparation of the paper.

References

[1] W. B. Boggs and J. N. Anderson: *Canadian Mining and Metallurgical Bulletin* (March 1930).

[2] W. B. Boggs and J. N. Anderson: *Trans.* AIME (1933) **106**, pp. 165-201.

[3] W. B. Boggs, J. N. Anderson, and W. L. Stevens: *Trans.* Canadian Inst. of Mining and Metallurgy (1939) **42**.

[4] W. B. Boggs, J. N. Anderson, and W. L. Stevens: *Trans.* Canadian Inst. of Mining and Metallurgy (1945) **47**, pp. 402-428.

[5] *Canadian Mining Journal* (May 1946) pp. 431-441.

[6] Leonard Larson: *Trans.* AIME (1944) **159**, pp. 20-27.

Technical Note

A Correction to "The Sigma Phase in Binary Alloys"

by Peter Greenfield and Paul A. Beck

RECENT work by J. Darby, Jr. in this laboratory has shown that the reported[1] vanadium-rich limit of the σ phase in the Co-V system at 1200°C is in error. The appearance of a second phase in σ actually is restricted to alloys containing over 68 atomic pct V. The error in the original value is due apparently to a reaction that takes place along the numerous cracks in the σ specimens between the alloy and the impurities present in the He + 8 pct H atmosphere in the annealing furnace. Such a reaction and the consequent appearance of a second phase can be suppressed if the alloys are sealed under vacuum in Vycor tubing.

The new value of 68 atomic pct V for the vanadium-rich limit of the σ phase in the Co-V system effects slightly the σ compositions calculated from average values of N_v and N_e for various σ phases.[1] The standard deviation between experimental mean compositions and those calculated from the assumption that σ is characterized by a constant number of $3d + 4s$ electrons per atom (N_e), is slightly reduced from 9.1 to 8.8 pct. The maximum divergence for the V-Mn σ phase is reduced from 15.5 to 14 atomic pct.

The standard deviation calculated from constant electron vacancy numbers given by

$$N_v = 4.66(\text{Mo} + \text{Cr} + \text{V}) + 3.2(\text{Mn}) + 2.2(\text{Fe}) + 1.71(\text{Co}) + 1.6(\text{Ni})$$

is now greatly reduced, as the maximum divergence for this correlation previously occurred in the V-Co system. This maximum divergence is reduced from 7.6 to 2.3 pct, and the standard deviation for all σ phases is reduced from 4.1 to only 2.9 pct.

The correlation for electron vacancy numbers given by

$$N_v\ 5.66\ (\text{V when with Ni or Co}) + 4.88\ (\text{V when with Mn or Fe}) + 4.66\ (\text{Cr} + \text{Mn}) + 3.3\ (\text{Mn}) + 2.66\ (\text{Fe}) + 1.71\ (\text{Co}) + 0.61\ (\text{Ni})$$

is made slightly worse, and the standard deviation increases from 2.8 to 3.9 pct. These changes, however, do not affect the conclusions of the paper.[1] The deviation between calculated and experimental σ compositions is much less for either one of the electron vacancy correlations than for the correlation with the number of $3d + 4s$ electrons.

[1] P. Greenfield and P. A. Beck: *Trans.* AIME (1954) **200**, p. 253; JOURNAL OF METALS (February 1954).

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TN 217E. Manuscript, March 5, 1954.

Activities of Fe, FeO, Fe_2O_3, and CaO in Simple Slags

by Hugo R. Larson and John Chipman

The data previously reported for the quantity $j = Fe^{+++}/(Fe^{++} + Fe^{+++})$ as a function of oxygen pressure at 1550°C have been used to compute the activities of Fe, FeO, Fe_2O_3, and CaO in slags of the ternary system. Activities of the first three have been obtained also for two quasi-ternaries involving fixed $CaO:SiO_2$ ratios.

IN a previous paper[1] the authors reported the results of an investigation into the effects of oxygen pressure on the composition of various simple slags analogous to some of those which are found in steelmaking practice. The ratio of ferric iron to total iron was studied at 1550°C in iron oxide melts to which lime, magnesia, lime-plus-silica, and other oxides were added. The oxygen pressures involved those of air, carbon dioxide, and carbon dioxide plus carbon monoxide in several proportions. Although very low oxygen pressures could not be used, the slag-metal equilibrium studies of Fetters and Chipman[2] permitted extending the results to slags in equilibrium with iron.

For the ternary system CaO-FeO-Fe_2O_3 the oxygen pressure-composition relationship has been determined from zero percent lime to lime saturation over an oxygen pressure range from air to that represented by equilibrium with liquid iron. Lime and silica were added to iron oxide in the ratios 0.54, 1.306, and 2.235 to form three quasi-ternary systems which were also studied over the entire region of liquid melts at 1550°C.

Ternary Gibbs-Duhem Equation

Wagner[3] has developed a method by which the activities of two components of a ternary system can be calculated if the activity of the third component is known throughout tne composition range being considered.

The fundamental form of the Gibbs-Duhem equation for ternary systems is $N_1\, d \ln a_1 + N_2\, d \ln a_2 + N_3\, d \ln a_3 = 0$. Wagner has developed a usable form of this equation by introducing the term $y = N_3/(N_3 + N_1)$ and rearranging the equation to give

$$\left(\frac{\partial \ln a_1}{\partial N_2}\right)_y = \frac{-y}{(1-N_2)^2}\left(\frac{\partial \ln a_2}{\partial y}\right)_{x_2} - \frac{N_2}{1-N_2}\left(\frac{\partial \ln a_2}{\partial N_2}\right)_y . \qquad [1]$$

To apply this equation to the slag system CaO-FeO-Fe_2O_3, the activity of one of these components must be known. However, the only activity which is known from the experimental data is the activity or pressure of oxygen in the gas phase with which tne slag is in equilibrium. The activity of oxygen in the slag can be defined as the square root of the oxygen pressure. In order to use oxygen as one component, the composition of the slags must be converted to the basis Fe-O-CaO. Oxygen, exclusive of that contained in CaO, then becomes component 2 in Eq. 1, Fe is selected as 1 and CaO as 3. Then $y = N_{CaO}/(N_{CaO} + N_{Fe})$. Eq. 1 then becomes

$$\left(\frac{\partial \ln a_{Fe}}{\partial N_O}\right)_y = \frac{-y}{(1-N_O)^2}\left(\frac{\partial \ln a_O}{\partial y}\right)_{x_O} - \frac{N_O}{1-N_O}\left(\frac{\partial \ln a_O}{\partial N_O}\right)_y . \qquad [2]$$

In order to evaluate Eq. 2, the boundary conditions must be known. The obvious choice of a standard state for iron is to assign slags in equilibrium with iron an activity of one. Then $\ln a_{Fe}$ or $\log a_{Fe}$, which is substituted for convenience, is determined by integrating along a line of constant y from the slag in equilibrium with iron to the composition at which $\log a_{Fe}$ is to be determined. Mathematically this can be expressed as

$$\log a_{Fe}\,(N_O, y) = \log a'_{Fe} + \int_{x'_O}^{x_O}\left(\frac{\partial \log a_{Fe}}{\partial N_O}\right)_y dN_O \qquad [3]$$

where the primes indicate equilibrium with liquid iron and $a'_{Fe} = 1$.

When Eq. 3 is integrated along a line of constant y, the following is obtained:

$$\log a_{Fe}\,(N_O, y) = -y\int_{x'_O}^{x_O}\frac{\partial}{\partial y}\left(\frac{\log a_O}{(1-N_O)^2}\right)_{x_O} d\,N_O - \int_{x'_O}^{x_O}\frac{N_O}{1-N_O}\,d \log a_O . \qquad [4]$$

Lime-Iron Oxide Slags

Iron Activity: The oxygen pressure of lime-iron oxide slags is shown in Fig. 1 as a function of j, defined as $j = Fe^{+++}/(Fe^{++} + Fe^{+++})$ for various constant mol percentages of lime. The j values at 0 to 60 pct lime were then determined for oxygen pressures of 1, 10^{-1}, etc. to 10^{-8} atm. For purposes of calculation, the line for zero percent lime was extrapolated to

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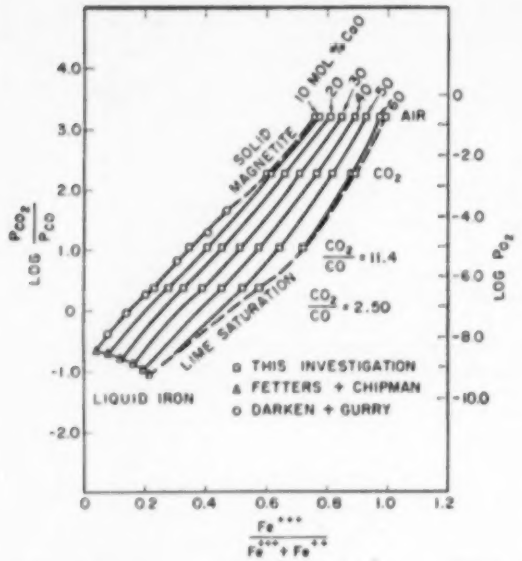

Fig. 1—Oxygen pressures in CaO-FeO-Fe_2O_3 slags at 1550°C.

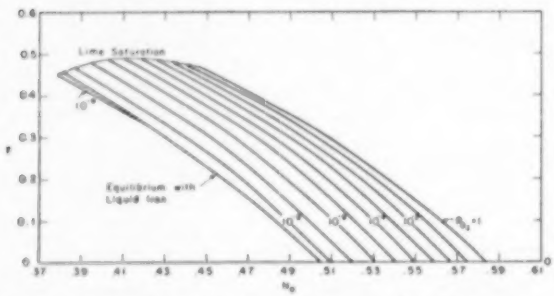

Fig. 2—Function $y = N_{CaO}/(N_{CaO} + N_{Fe})$ vs mol fraction oxygen (exclusive of CaO) at constant oxygen pressures.

higher oxygen pressures. Since the lines of Fig. 1 are relatively straight, there is little uncertainty in extrapolating and the calculations are simplified.

These slag compositions expressed as j and mol percent lime were recalculated to the basis Fe-O-CaO to permit their application in Eq. 4. Since the composition of a ternary system is fixed by the concentration of one component and the ratio of the other two, these compositions were expressed as N_o and y (as defined above).

These latter values have been plotted in Fig. 2 where each line represents a constant value of log a_o. The two terms in Eq. 4 were evaluated by reading the appropriate values from Fig. 2 and performing the various differentiations and integrations by graphical methods. The calculated values of log a_{Fe} are plotted against N_{Fe} for different values of y in Fig. 3. The compositions of slags for which log a_{Fe} is 0, −1, etc. to −5 were converted to the basis CaO-FeO-Fe_2O_3 and the results are plotted in Fig. 4 as lines of constant iron activity.

It is difficult to estimate the accuracy of the calculations. The first term in Eq. 4, involving differentiation before the integration, is certainly the least accurate. Since it is multiplied by y, the accuracy decreases as y increases, i.e., at higher lime contents.

As a check on the calculated activity of iron, experiments were performed utilizing the fact that iron dissolved in the platinum crucibles in an amount which depended upon the iron activity of the slags. Platinum foils were equilibrated with slags of different lime contents but with the atmosphere adjusted to give the same iron activity. If the same iron content were found in the platinum, the calculated iron activities would be verified. These experiments were carried out in groups of 3 to 5 foils at four levels of iron activity. On a plot of the activity vs mol fractions of iron, the maximum deviation in mol fraction was ± 0.01. The results have been utilized[4] to obtain the activity coefficient of Fe in the solid solution Pt-Fe.

Lime Activity: It would be possible to calculate the lime activities in precisely the same manner as the iron activities were determined. However, an easier method is available. The fundamental form of the Gibbs-Duhem equation for this ternary system is $N_{Fe}\, d \ln a_{Fe} + N_o\, d \ln a_o + N_{CaO}\, d \ln CaO = 0$. Along a line of constant oxygen activity, the equation reduces to $N_{Fe}\, d \ln a_{Fe} + N_{CaO}\, d \ln a_{CaO} = 0$. If the activity of CaO is based on pure solid lime, it becomes

$$\log a_{CaO} = -\int_{N_{CaO(sat.)}}^{N_{CaO}} \frac{N_{Fe}}{N_{CaO}}\, d \log a_{Fe}$$

The necessary data are available from Fig. 3. The plotted points can be connected by lines of constant oxygen activity which are approximately parallel to the horizontal axis. The integrations were performed on the data along oxygen pressure lines of 1, 10^{-2}, 10^{-4}, 10^{-6}, and 10^{-8} atm. For each of these constant pressures, the activity of lime was plotted against the mol fraction of lime. The compositions with lime activities of 1.0, 0.8, 0.6, 0.4, 0.2, and 0.1 were read from these curves. The appropriate concentrations were marked off on the oxygen pressure lines of Fig. 4 and the points were joined by lines of constant lime activity.

The lime activities along the line representing slags in equilibrium with iron were also determined by an independent calculation. Since the activity of iron is constant, the ternary Gibbs-Duhem equation reduces to

$$N_{CaO}\, d \log a_{CaO} + N_o\, d \log a_o = 0.$$

Therefore,

$$d \log a_{CaO} = -\frac{N_o}{N_{CaO}}\, d \log a_o \cdot$$

The variation of log a_o (= ½ log P_{O_2}) with composition along this line of iron saturation is shown in Fig. 1. When the integration was carried out, the

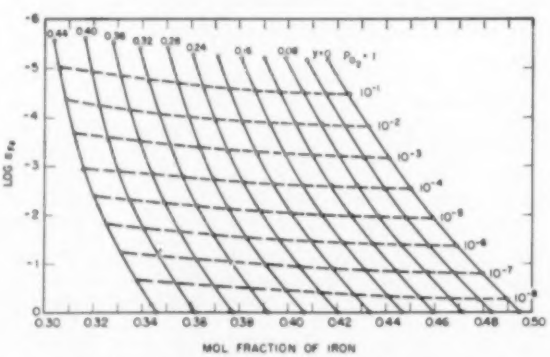

Fig. 3—Activity of iron as a function of slag composition, expressed as N_{Fe} and y.

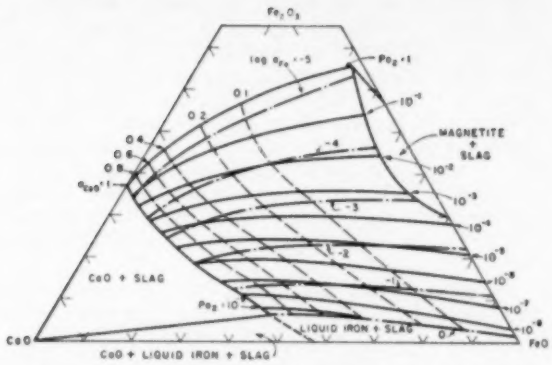

Fig. 4—Activities of O, Fe, and CaO in the system CaO-FeO-Fe_2O_3. Compositions in mol fraction.

points for $a_{CaO} = 0.8$, 0.6, etc. were in satisfactory agreement with the lines of constant lime activity shown in Fig. 4.

Activity of Ferrous Oxide: The calculation of iron activity shown in previous sections is permissible from a thermodynamic standpoint. However, since slags are usually considered in terms of oxides rather than elements, it is desirable to calculate the activities of ferrous and ferric oxides. In addition the activity of iron changes rapidly with composition, in fact by a factor of 100,000 in the range from iron saturation to an oxygen pressure of 1 atm. The activity of ferrous oxide, defined as the product of the activities of iron and oxygen, changes much less rapidly over the same range.

The data necessary for this calculation have been plotted in Fig. 3. The value of $\log a_{Fe} + \log a_O$ was determined for each of the slags represented by the plotted points. The standard state was selected as the hypothetical stoichiometric FeO. The value of $\log a_{Fe} + \log a_O$ in the standard state was determined by plotting these values for pure iron oxide slags (i.e., zero percent lime) against the mol fraction of FeO. This procedure gave a value of −4.272 for $(\log a_{Fe} + \log a_O)$ in the standard state, where $a_O = p_{O_2}^{1/2}$. The activity of FeO based on pure FeO could then be determined by subtracting this extrapolated value from the value of $\log a_{Fe} + \log a_O$ for each of the slags.

For each group of slags with a constant value of y as shown in Fig. 3, the activity of FeO was plotted against the mol fraction of FeO. Compositions corresponding to $a_{FeO} = 0.9$, 0.8, etc. were picked off and plotted in Fig. 5 as lines of constant FeO activity.

Activity of Ferric Oxide: The activity of ferric oxide was determined in a somewhat analogous manner.

$a_{Fe_2O_3} = a^2_{Fe} \times a^3_O$, $\log a_{Fe_2O_3} = 2 \log a_{Fe} + 3 \log a_O$.

Since none of the slags approaches the composition Fe_2O_3, some other standard state than the pure compound must be chosen. The standard state was established by making the activity of Fe_2O_3 in the pure iron oxide slag in equilibrium with iron equal to its mol fraction. The values of $\log a_{Fe_2O_3}$ based on this standard state were plotted against the mol fraction of Fe_2O_3 for each group of slags with constant y. Slags with activities from 0.005 to 5 were plotted in Fig. 5 as lines of constant ferric oxide activity.

Lime-Silica-Iron Oxide Slags

Three master lime-silica slags were made which had lime:silica ratios of 2.235, 1.306, and 0.540. These were melted with varying additions of iron oxide under the same atmospheres used in the study of lime-iron oxide slags. The experimental results, expressed as $j = Fe^{+++}/(Fe^{+++} + Fe^{++})$ vs mol percent of lime + silica, were presented in the previous paper.[1]

Slags in Equilibrium with Iron: Since very reducing atmospheres could not be used in these experiments, the data of Fetters and Chipman[2] have been used to obtain the composition and oxygen pressure of the slags in equilibrium with iron. However, since these included only a few slags which had lime:silica ratios sufficiently close to the above ratios, the procedure used for lime-iron oxide slags was modified.[1]

Fetters and Chipman plotted in their Fig. 5 lines of constant ferric oxide content on the ternary diagram $(MgO + CaO) - SiO_2 - FeO_{(total)}$. Lines were drawn from the iron oxide corner of the diagram which had lime:silica ratios of 1.306 and 2.235. The intersections with lines of constant ferric oxide content were determined, and the compositions were expressed as j vs mol percent lime-plus-silica. Similarly the oxygen content of the metal was read from the appropriate diagram for the same lime:silica ratios, and the equilibrium CO_2/CO ratios of Darken and Gurry[5] were used again to establish gas compositions in equilibrium with the slags. It was thus possible to obtain, for the lime:silica ratios 1.306 and 2.235, curves (not shown here) corresponding to Figs. 4, 5, and 6 of the previous paper. Similar data for the ratio 0.540 were not available. It should be pointed out that this procedure is less satisfactory than in the case of the simple ternary system. Not only was the magnesia content of their

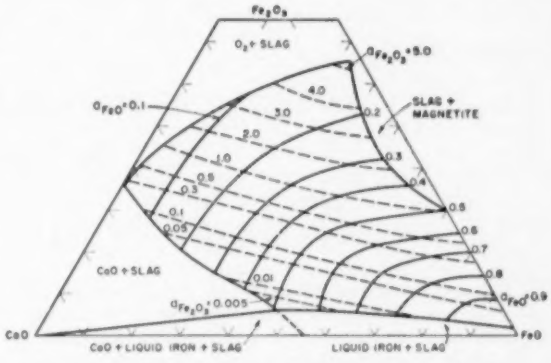

Fig. 5—Activities of FeO and Fe_2O_3 in the system CaO-FeO-Fe_2O_3. Compositions in mol fraction.

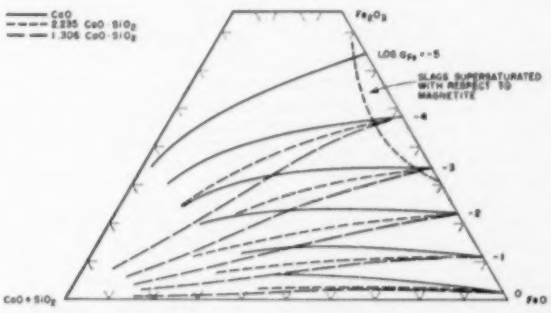

Fig. 6—Activity of iron in lime-silica-iron oxide slags at 1550°C. Compositions in mol fraction.

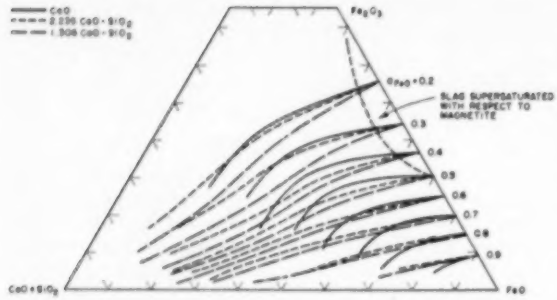

Fig. 7—Activity of FeO in lime-silica-iron oxide slags at 1550°C. Compositions in mol fraction.

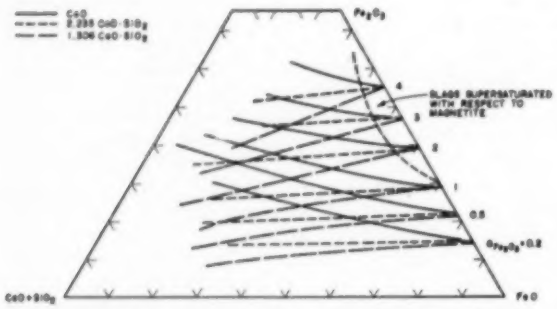

Fig. 8—Activity of Fe_2O_3 in lime-silica-iron oxide slags at 1550°C. Compositions in mol fraction.

slags higher, but also the interpolation in the diagrams of Fetters and Chipman is less certain.

Activity of Iron: In a lime-silica-iron oxide system in which the ratio of lime to silica remains constant, the two can be treated together as one component. Thus the two quasi-ternary systems $1.306CaO \cdot SiO_2$ — FeO — Fe_2O_3 and $2.235CaO \cdot SiO_2$ — FeO — Fe_2O_3 are amenable to the same kind of activity calculations as those already applied to simple lime-iron oxide slags. The results of these calculations are shown in Fig. 6 as lines of constant iron activity.

The activities of ferrous and ferric oxide were determined as already described for lime-iron oxide slags. The results are shown in Figs. 7 and 8.

Acknowledgments

The authors wish to thank D. L. Guernsey and his associates for the analytical work, and the Republic Steel Corp. for a fellowship grant which made the research possible.

References

[1] Hugo Larson and John Chipman: *Trans.* AIME (1953) **197**, p. 1089; JOURNAL OF METALS (September 1953).

[2] K. L. Fetters and J. Chipman: *Trans.* AIME (1940) **140**, p. 170.

[3] Carl Wagner: *Thermodynamics of Alloys.* (1952) p. 19. Addison-Wesley Press.

[4] Hugo Larson and John Chipman: Activity of Iron in Iron-Platinum Solid Solutions. *Acta Metallurgica* (1954) **2**, p. 1.

[5] L. S. Darken and R. W. Gurry: *Journal* ACS (1946) **68**, p. 798.

Technical Note

Purification of Antimony and Tin by a New Method Of Zone Refining

by M. Tanenbaum, A. J. Goss, and W. G. Pfann

THE purification of two metals, antimony and tin, by zone refining is described, and a reciprocating method of passing molten zones through a straight ingot, which effects a considerable economy of time and apparatus, is discussed.

Antimony has been used extensively as a doping agent in germanium and silicon. More recently, it has become important in the preparation of new semiconducting compounds such as InSb, GaSb, and AlSb. High purity is especially necessary in this latter use, since the antimony may comprise as much as 80 pct by weight of the compound. Antimony is generally available in a commercial form of about 99.8 pct purity. Column 1 of Table I is a typical emission spectra analysis of commercially available 99.8 pct antimony.

Zone refining has been quite successful in increasing the purity of such samples. Columns 2 to 4 of Table I are analyses of an ingot of the antimony of column 1 after the passage of seven molten zones in an atmosphere of nitrogen. The ingot length was 9½ in.; the mean zone length was 2 in.; convection was the only means of stirring. The column headings are sample locations in inches from the leading end of the ingot. The results illustrate both the merit and a limitation of zone refining. It is seen that four of the five impurities—nickel, arsenic, lead,

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Table I. Spectrographic Analyses of Zone Refined Antimony*

Concentration, Wt Pct	(1) As-received	(2) 0 In.	(3) 4 In.	(4) 7½ In.
>10	Sb	Sb	Sb	Sb
>1	—	—	—	—
0.01-0.3	Ni, Pb, As	As	As	As, Pb
<0.03	Ag, Cu	—	Cu, Fe, Pb	Ag, Cu, Fe, Ni
<0.005	Fe, Si, Sn	Mg, Si, Pb	Ag, Mg, Ni	Mg, Si, Sn
<0.001	—	Cu, Sn	Si, Sn	—

* We are indebted to E. K. Jaycox, N. B. Hannay, W. Hartmann, A. J. Ahearn, and J. P. Wright for analytical results.

Table II. Analyses of Zone Refined Tin

Material	Location in Ingot	Weight, Pct		
		Pb	Cu*	Fe
As-received	—	0.001	0.00003	0.0005
As-zone refined	Beginning	<0.0001	0.00002	0.0002
As-zone refined	Middle	<0.0001	0.00001	0.0004
As-zone refined	End	~0.03	0.00010	0.0020

* Values are relative rather than quantitative, but are known to be <0.0002.

silver, and copper—have been reduced in concentration by factors of the order of a decade or more at the pure end of the ingot. Two, nickel and silver, were not detectable. Arsenic, however, was not removed from the leading end, which was expected, as the As-Sb phase diagram indicates that the equilibrium distribution coefficient is close to unity.

To prepare antimony with an extremely low arsenic content, chemical purification was used. Chemically pure antimony trichloride was distilled from a hydrochloric acid solution and reduced with carbonyl iron. The metallic antimony was then zone refined. After ten zone passes, the only impurities found, by mass spectroscopy, were zinc and arsenic in concentrations of about 1 part in 10 million.

Zone refining has also been successfully applied to tin. The metal was initially of high purity, 99.99+ pct, and further purification was achieved by passing 40 molten zones through a 100 gram, 10 in. ingot sealed in vacuum in a pyrex tube.

The mean zone length was 1½ in. Spectrographic and chemical analyses were made. Despite the difficulties of the quantitative measurements, they show clearly that lead, copper, and iron, the only metallic impurities detected, were segregated at the end of the ingot. It is likely that fewer zone passes would have sufficed, but at the present time a minimum number has not been established.

The reciprocating heater method described as method 3 below was used in these experiments. It produces zone travels with greater overall economy of time and apparatus than the perhaps more conventional methods with which it is compared. Therefore, it makes feasible experiments or processes which might not otherwise be attempted. A given number, P, of molten zones can be made to pass through a straight ingot of length, L, in the following ways which are equivalent in purifying effect:

1—By P passes through a single heater, as in Fig. 1a. The main objection to this method is that it wastes time.

2—By one pass through P heaters, as in Fig. 1b, which method does the job in the least possible time but in which the length of the refiner, the number

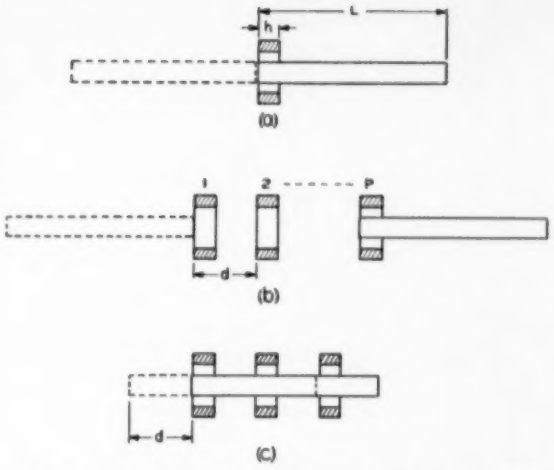

Fig. 1—Methods of passing P molten zones through an ingot of length L: a—One heater, P passes; b—P heaters, one pass; c—L/d heaters, $P + (L/d) - 1$ reciprocating strokes of length d. Ingot is shown full at beginning, dashed at end, of cycle.

of heaters, and the heater power are unduly great, particularly if P is large.

3—By a series of short reciprocating strokes, using N heaters, as in Fig. 1c, where $N = L/d$ and where the stroke length is equal to the heater interval, d. A stroke begins with the leading edge of the ingot about to emerge from the first heater. The ingot is advanced slowly, with respect to the heaters, a distance d, whereupon it is rapidly returned to its starting position, transferring each molten zone to the next heater. Repetitions of this cycle can effect the passage of any number of molten zones through the ingot.

These three methods are compared in Table III with respect to four processing parameters of economic importance. Rows 1 to 3 contain general expressions for length of refiner, number of heaters, refining time, and heater energy required to pass P zones through an ingot of length L. In rows 4 to 6 the numerical values of these parameters are shown for the case $P = 10$, $L = 9$, $h = 1$, $d = 3$. It can be seen that the reciprocating heater method is markedly superior to method 2 in three categories and to method 1 in the all-important time category. Furthermore, its margin of superiority increases with P.

These considerations apply particularly to ingots of straight form, which is probably the most convenient form to work with. It should be pointed out, however, that all of the advantages of method 3 can be obtained, without reciprocating motion, by using a circular ingot as shown in Fig. 12 of ref. 1.

[1] W. G. Pfann: Principles of Zone-Melting. *Trans.* AIME (1952) 194, p. 747; JOURNAL OF METALS (July 1952).

Table III. Process Parameters for Three Methods of Zone Refining

Row	Method	Length of Refiner		Number, N, of Heaters	Time, t, Rel. Units	Heater Energy Nt, Rel. Units
		Ingot Moving	Heaters Moving			
1	1—One-heater	$2L$	$L + h$	1	PL	PL
2	2—One-pass	$2L + (P-1)d$	$L + 2(P-1)d$	P	$L + (P-1)d$	$P[L + (P-1)d]$
3	3—Reciprocating	$L + d$	$L + h$	L/d	$L + (P-1)d$	$(L/d)[L + (P-1d]$
4	1—One-heater	18	10	1	90	90
5	2—One-pass	45	63	10	36	360
6	3—Reciprocating	12	10	3	36	108

Creep Rupture Properties and Structural Changes In Carbon and Low Alloy Steels

by A. B. Wilder, E. F. Ketterer, and D. B. Collyer

The microstructural stability of 59 carbon and low alloy steels after 34,000 hr exposure at 900° and 1050°F, including the weld heat-affected zone, is discussed. The tensile and creep rupture properties of the parent metal of many of the steels before and after 10,000 hr exposure are presented.

SEAMLESS pipe has been used for many years at elevated temperatures. When seamless first began to be used, operating temperatures and pressures were relatively low and the steel produced adequately met the existing requirements. The need for knowledge of creep properties and graphitization was nonexistent. Today the requirements for tubular products have changed considerably. Operating temperatures and pressures are increasing continually and corrosion, particularly at high temperatures, presents a problem. Carbon steels have, under these conditions, certain economic advantages particularly in oil refinery use. However, the use of low alloy steels in the generation of steam power has increased appreciably due to the influence of molybdenum on creep strength and the control of graphitization with chromium.

The behavior of carbon and certain low alloy steels after long periods of exposure at 900° and 1050°F (480° and 565°C) has been investigated. The steels were examined before and after 10,000 to 34,000 hr exposure. Results obtained with material exposed at 1200°F (650°C) are not presented due to the severe oxidation and resulting decarburization after long periods of exposure.

The graphitization characteristics of carbon and low alloy steels are of fundamental concern to the users of these materials. This is particularly true where welded joints are employed. In order to evaluate properly the behavior of steels at elevated temperatures, it is desirable to employ not only long periods of exposure under controlled conditions, but to use material with known properties and steelmaking practices.

The purpose of this investigation has been to study the microstructure of the weld and the tensile and creep rupture properties of the parent metal after long periods of exposure at elevated temperatures. In the report[1-3] of a previous investigation data were presented on the microstructure, impact strength, hardness, and oxidation characteristics after 10,000 hr exposure at elevated temperatures.

When this investigation was planned, methods for controlling the graphitization characteristics of steel were not established and, therefore, a number of special alloy steels were included in the study. During the exposure of these steels, the influence of aluminum in accelerating the rate of graphitization and the inhibiting power of chromium were established by various investigators. Also, the vanadium-bearing steels, because of their outstanding creep properties, received attention. As a result of these developments, considerable progress has been made in the field of high temperature tubular products, and the necessity for special alloys to prevent graphitization has been restricted largely to the use of chromium.

Material

Chemical analysis, deoxidation treatment, and austenitic grain size of the 59 steels discussed in this paper are shown in Table I. The steels were forged to 1x1 in. bars with the exception of steels 12B, 12DX, 12DY, 12DZ, 70, 70A, 72 to 78, 82, and 83 which were machined from heavy wall pipe. All bars were surface ground before exposure. Heat treatment before exposure is shown in Table II. The majority of the steels included were melted in either a basic open hearth or basic electric furnace; how-

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ever, some of the steels were melted in a laboratory induction furnace.

Procedure for Testing

Exposure Furnaces: All samples were exposed at 900°, 1050°, and 1200°F (480°, 565°, and 650°C) in electric furnaces without atmosphere control.

Weld Bead Tests: Two 6 in. weld beads[3] with different heat inputs were deposited at U. S. Steel Corp. Research Laboratory on opposite sides of a 1x1x6 in. bar. Results with the small weld bead deposited from a ⅛ in. diameter electrode using 100 amp at 24 v and an arc travel speed of 10 in. per min are reported in this investigation. The preheat, postheat, and type of electrodes used are shown in Table II. All welds, including steels 40D and 41D, except class 1 (carbon steels), were preheated at 500°F (260°C) and postheated at 1200°F (650°C).

Graphitization Chart: A transverse section of the weld bead samples was examined microscopically as follows: zone 1, in the coarsened structure immediately beneath the weld metal; zone 2, in the relatively fine grain structure beneath zone 1; zone 3, near the boundary of the heat-affected zone where the grain size is similar to the parent metal; and zone 4, in the unaffected parent metal. Results are reported after 34,000 hr exposure at 900° and 1050°F (480° and 565°C) for the small weld bead, except for steel 82 which was exposed only 10,000 hr. The graphitization chart,[4] containing designations A, B, C, etc. (A being the smallest size particle), was used. A rating of 10C, for example, indicates 10 particles of dispersed graphite with an average size C in a 4x5 in. field at magnifications of 500.

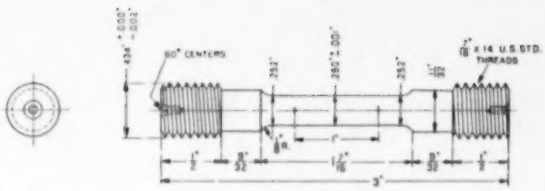


Fig. 1—Test specimen.

Tensile and Creep Rupture Tests: The tensile and creep rupture specimen is shown in Fig. 1. Tensile tests after exposure were made at room temperature. Creep rupture tests were made at 900° and 1050°F (480° and 565°C) after 10,000 hr exposure at these temperatures in accordance with the procedure and facilities which have been described.[5] Most of the rupture data were based on tests of several hours duration to approximately 1000 hr, and the values for 10,000 hr were obtained by extrapolation.

Creep Rupture Properties

The creep rupture properties are summarized in Table III and Figs. 2 and 3. The identification of

Table I. Chemical Composition of Carbon Steels

No.	Type	Process*	Deoxidation, Lb Al per Net Tons of Ingots	C	Mn	P	S	Si	Al	N	Mo	Cr	Ni	Cu	Others
1	Capped	O.H.	Capped	0.07	0.40	0.008	0.030	—	0.003	0.005	0.004	0.026	0.006	0.01	—
2	Capped	B	Capped	0.10	0.55	0.077	0.028	—	0.005	0.016	0.001	0.010	0.004	0.01	—
3A	Carbon	B	4	0.16	0.50	0.079	0.028	0.014	0.031	0.017	0.006	0.014	0.006	0.01	—
3D	Carbon	B	3	0.15	0.51	0.074	0.022	0.156	0.023	0.020	0.003	0.013	0.005	0.01	—
4A	Carbon	B	4	0.24	0.61	0.072	0.021	0.199	0.044	0.018	0.003	0.009	0.010	0.02	—
4D	Carbon	B	3	0.25	0.58	0.069	0.022	0.161	0.044	0.019	0.003	0.008	0.010	0.02	—
5A	Carbon	O.H.	1.8	0.17	0.46	0.009	0.029	0.028	0.025	0.005	0.004	0.092	0.007	0.01	—
5B	Carbon	O.H.	0	0.20	0.57	0.011	0.032	0.224	0.006	0.005	0.004	0.023	0.005	0.01	—
5C	Carbon	O.H.	0.4	0.19	0.45	0.016	0.023	0.249	0.003	0.006	0.005	0.043	0.007	0.01	—
5D	Carbon	O.H.	1.4	0.20	0.37	0.010	0.038	0.257	0.024	0.005	0.004	0.022	0.006	0.01	0.0003 Ti
5E	Carbon	O.H.	1.2 lb Al 0.3 lb Ti	0.18	0.40	0.007	0.021	0.032	0.016	0.004	0.003	0.022	0.007	0.01	0.006 Ti
6A	Carbon	O.H.	1.4	0.27	0.54	0.008	0.028	0.054	0.032	0.005	0.004	0.038	0.009	0.02	—
6D	Carbon	O.H.	1.4	0.26	0.48	0.007	0.025	0.269	0.029	0.006	0.006	0.026	0.011	0.01	0.0003 Ti
6E	Carbon	O.H.	0.8 lb Al 0.3 lb Ti	0.26	0.54	0.007	0.032	0.048	0.008	0.005	0.006	0.026	0.009	0.01	0.006 Ti
40D	Resulphurized	O.H.	3.0	0.16	1.65	0.020	0.121	0.062	0.047	0.011	0.004	0.008	0.009	0.01	—
41D	Resulphurized	O.H.	1.4	0.37	1.51	0.012	0.129	0.236	0.023	0.006	0.003	0.006	0.009	0.01	—
73	0.5 Cr-0.5 Mo	E	0.5	0.14	0.47	0.012	0.019	0.205	0.003	0.009	0.50	0.48	0.06	0.03	—
74	0.5 Cr-0.5 Mo	E	0.13	0.11	0.54	0.010	0.023	0.153	0.003	0.009	0.52	0.49	0.14	0.08	—
79	0.5 Cr-0.5 Mo-Al	I	4	0.18	0.44	0.011	0.033	0.250	0.17	0.007	0.54	0.06	0.06	0.02	—
80	0.5 Cr-0.5 Mo-Al	I	4	0.18	0.50	0.010	0.030	0.260	0.17	0.007	0.56	0.55	0.06	0.03	—
82	0.5 Cr-0.5 Mo	E	0.5	0.14	0.48	0.012	0.018	0.180	0.005	0.011	0.48	0.51	0.08	0.02	—
70	1 Mo-0.25 V	E	0.5	0.20	0.58	0.013	0.017	0.270	0.004	0.011	0.99	0.09	0.06	0.02	0.22 V
70A	1 Mo-0.25 V	E	0.5	0.20	0.58	0.013	0.017	0.270	0.004	0.011	0.99	0.09	0.06	0.02	0.22 V
81	0.5 Cr-1 Mo-0.25 V	I	0	0.13	0.36	0.007	0.038	0.240	0.009	0.009	1.03	0.56	0.05	0.02	0.23 V
81A	0.5 Cr-1 Mo-0.25 V	I	0	0.13	0.36	0.007	0.038	0.240	0.009	0.009	1.03	0.56	0.05	0.02	0.23 V
10D	0.25 Cr-0.5 Mo-P	I	2	0.13	0.46	0.099	0.020	0.145	0.043	0.006	0.51	0.23	0.014	0.06	0.0003 Ti
11D	0.25 Cr-0.5 Mo-Ti	I	2	0.13	0.48	0.025	0.020	0.180	0.059	0.007	0.50	0.24	0.023	0.07	0.07 Ti
13D	0.5 Cr-1 Mo-P	I	2	0.11	0.42	0.156	0.020	0.114	0.043	0.006	1.01	0.46	0.032	0.06	0.0003 Ti
14D	0.5 Cr-1 Mo-P-Ti	I	2	0.13	0.49	0.152	0.018	0.172	0.070	0.007	1.01	0.50	0.11	0.07	0.11 Ti
58	0.5 Cr-0.5 Mo-P	E	0	0.15	0.42	0.116	0.037	0.140	0.011	0.006	0.66	0.47	0.03	0.02	—
59	0.5 Cr-0.5 Mo-P	E	1.25	0.19	0.49	0.118	0.035	0.200	0.044	0.007	0.64	0.50	0.03	0.02	—
44	C-Zr	I	16.25 lb Si-Ti-Zr	0.20	0.58	0.006	0.022	0.222	0.007	0.006	0.03	0.014	0.059	0.02	0.023 Ti 0.10 Zr
45	C-Zr-0.5 Mo	I	16.25 lb Si-Ti-Zr	0.19	0.49	0.006	0.023	0.290	0.006	0.007	0.51	0.011	0.061	0.06	0.032 Ti 0.13 Zr
60	C-0.5 Mo	I	2.5	0.08	0.50	0.016	0.028	0.293	0.029	0.007	0.57	0.020	0.023	0.02	No Ti
61	0.5 Mo-0.5 Ti	I	2.5	0.09	0.60	0.018	0.029	0.425	0.031	0.006	0.56	0.064	0.025	0.04	0.47 Ti
62	1 Mo-0.5 Ti	I	2.5	0.10	0.60	0.018	0.030	0.348	0.032	0.006	0.95	0.056	0.025	0.04	0.50 Ti
63	0.5 Mo-0.25 Ti	I	2.5	0.09	0.61	0.016	0.027	0.359	0.034	0.006	0.53	0.043	0.025	0.03	0.25 Ti
64	1 Mo-0.25 Ti	I	2.5	0.09	0.61	0.016	0.029	0.344	0.033	0.006	1.05	0.046	0.025	0.03	0.25 Ti
65	0.5 Mo-1 Cb	I	2.5	0.08	0.60	0.015	0.027	0.378	0.047	0.007	0.52	0.019	0.025	0.01	0.003 Ti 1.08 Cb
66	1 Mo-1 Cb	I	2.5	0.08	0.62	0.016	0.028	0.434	0.046	0.006	0.98	0.022	0.024	0.01	0.006 Ti 1.12 Cb
67	2 Ni-Cu-Ti	I	3	0.09	0.62	0.016	0.028	0.200	0.124	0.006	0.005	0.02	1.89	0.73	0.36 Ti
68	0.5 Ni-0.5 Mo-Ti	I	3	0.08	1.49	0.020	0.024	0.200	0.126	0.007	0.55	0.01	0.56	0.07	0.37 Ti
69	0.75 Mo-Cu-Ti	I	3	0.06	0.50	0.018	0.029	0.185	0.128	0.007	0.70	0.05	0.02	0.70	0.37 Ti

Note: 70, 70A, 73, 74, and 82 were pipe samples. All other samples were forged bars.
* O.H., basic open hearth. B, acid bessemer. E, commercial basic electric furnace. I, laboratory induction furnace.

additional steels referred to for comparison purposes in the creep rupture and tensile test data is shown in Table IV. With reference to the carbon steels (group I), the creep rupture strength of bessemer steel after 10,000 hr exposure at 900° or 1050°F (480° or 565°C) is equivalent or superior to open hearth steel. Before exposure the silicon-killed open hearth steel and capped bessemer steel had higher creep rupture strength, but this was reduced after exposure. It has been recognized for many years that straight silicon-killed open hearth steel has superior creep rupture properties. The data presented in this paper indicate that after long periods of exposure steels with various types of deoxidation practice have similar creep rupture properties.

The creep rupture ductility properties for the carbon steels are shown in Fig. 2. Although the elongation and reduction of area were in certain instances increased and in others decreased, the properties in general are satisfactory for most engineering applications.

The creep rupture properties of the C-0.5 pct Mo steels were not appreciably changed after 10,000 hr exposure at 900°F (480°C), but the properties were appreciably reduced after 10,000 hr exposure at 1050°F (565°C). This would indicate that these steels are more stable at the lower temperatures. Variations in deoxidation practice did not appreciably affect the creep rupture properties. The creep rupture strength of the C-1 pct Mo steel was superior to the C-0.5 pct Mo steel, particularly after 10,000 hr exposure. The creep rupture properties of the C-1 pct Mo steel after 10,000 hr exposure indicate the superior strength of this material and support the current practice of using higher working stresses. The creep rupture ductility characteristics of the C-Mo steels were not appreciably changed at 900°F (480°C) but were increased at 1050°F (565°C). The ductility properties of group II steels

Table II. Heat Treatment and Welding Electrode

No.	Type	Heat Treatment Before Exposure	Grain Size Before Exposure		Welding Electrode	Post-welding Heat Treatment
			Ferritic	Austenitic		
1	Capped	1650°F normalized	5-6	1-3	E-6010	None
2	Capped	1650°F normalized	5-7	1-3	E-6010	None
3A	Carbon	1650°F normalized	7-8	6-8	E-6010	None
3D	Carbon	1650°F normalized	7	6-8	E-6010	None
4A	Carbon	1650°F normalized	7-8	6-8	E-6010	None
4D	Carbon	1650°F normalized	7-8	6-8	E-6010	None
5A	Carbon	1650°F normalized	6-7	6-8	E-6010	None
5B	Carbon	1650°F normalized	6-7	1-3	E-6010	None
5C	Carbon	1650°F normalized	6-7	1-3	E-6010	None
5D	Carbon	1650°F normalized	7-8	6-8	E-6010	None
5E	Carbon	1650°F normalized	7-8	6-8	E-6010	None
6A	Carbon	1650°F normalized	7-8	6-8	E-6010	None
6D	Carbon	1650°F normalized	7-8	6-8	E-6010	None
6E	Carbon	1650°F normalized	7-8	85 pct 1-3 15 pct 5-7	E-6010	None
40D	Resulphurized	1650°F normalized	7-8	6-8	E-6010	500°F preheat 1200°F postheat
41D	Resulphurized	1650°F normalized	6-8	6-8	E-6010	500°F preheat 1200°F postheat
73	0.5 Cr-0.5 Mo	Pipe, stress-relieved 1200°F	5-6 ferrite, coarse carbide areas	1-3	E-7010	500°F preheat 1200°F postheat
74	0.5 Cr-0.5 Mo	Pipe, stress-relieved 1200°F	5-6 ferrite, coarse carbide areas	1-3	E-7010	500°F preheat 1200°F postheat
79	0.5 Cr-0.5 Mo-Al	1650°F normalized	7	6-8	E-7010	500°F preheat 1200°F postheat
80	0.5 Cr-0.5 Mo-Al	1650°F normalized	7-8	6-8	E-7010	500°F preheat 1200°F postheat
82	0.5 Cr-0.5 Mo	Pipe, stress-relieved 1200°F	4-5	Few 1 Balance 2-4	E-7010	500°F preheat 1200°F postheat
70	1 Mo-0.25 V	As-rolled pipe	10 pct fine ferrite grains (6-7) 90 pct coarse carbide areas	7-8	E-7010	500°F preheat 1200°F postheat
70A	1 Mo-0.25 V	Pipe, stress-relieved*	Fine ferrite, coarse carbide areas	7-8	E-7010	500°F preheat 1200°F postheat
81	0.5 Cr-1 Mo-0.25 V	1650°F normalized	7	7-8	E-7010	500°F preheat 1200°F postheat
81A	0.5 Cr-1 Mo-0.25 V	Stress-relieved*	Fine ferrite, coarse carbide areas	7-8	E-7010	500°F preheat 1200°F postheat
10D	0.25 Cr-0.5 Mo-P	1650°F normalized	6-7	80 pct 1-3 20 pct 6-8	E-7010	500°F preheat 1200°F postheat
11D	0.25 Cr-0.5 Mo-Ti	1650°F normalized	7-8	6-8	E-7010	500°F preheat 1200°F postheat
13D	0.5 Cr-1 Mo-P	1650°F normalized	7-8	85 pct 2-4 15 pct 6-8	E-7010	500°F preheat 1200°F postheat
14D	0.5 Cr-1 Mo-P-Ti	1650°F normalized	7-8	6-8	E-7010	500°F preheat 1200°F postheat
58	0.5 Cr-0.5 Mo-P	1650°F normalized	7-8	3-5	E-7010	500°F preheat 1200°F postheat
59	0.5 Cr-0.5 Mo-P	1650°F normalized	7-8	6-8	E-7010	500°F preheat 1200°F postheat
44	C-Zr	1650°F normalized	7-8	6-8	E-6010	None
45	C-Zr-0.5 Mo	1650°F normalized	7-8	6-8	E-7010	500°F preheat 1200°F postheat
60	C-0.5 Mo	1650°F normalized	5-7	5-7	E-7010	None
61	0.5 Mo-0.5 Ti	1650°F normalized	6-7	6-8	E-7010	None
62	1 Mo-0.5 Ti	1650°F normalized	5-7	6-8	E-7010	None
63	0.5 Mo-0.25 Ti	1650°F normalized	7	6-8	E-7010	None
64	1 Mo-0.25 Ti	1650°F normalized	6-7	6-8	E-7010	None
65	0.5 Mo-1 Cb	1650°F normalized	6-7	6-8	E-7010	None
66	1 Mo-1 Cb	1650°F normalized	6-7	6-8	E-7010	None
67	2 Ni-Cu-Ti	1650°F normalized	7-8	7-8	E-7020	500°F preheat 1200°F postheat
68	0.5 Ni-0.5 Mo-Ti	1650°F normalized	7-8	8	E-7026	500°F preheat 1200°F postheat
69	0.75 Mo-Cu-Ti	1650°F normalized	6-7	7-8	E-7010	500°F preheat 1200°F postheat

* 70A and 81A heated 2 hr 1925°F (1050°C), furnace cooled to 1750°F (950°C), then air cooled; stress-relieved 4 hr 1300°F (700°C), then air cooled.

were, in general, at a lower level compared with the carbon steels of group I.

The creep rupture properties of the Cr-0.5 pct Mo steels were, in general, similar to the C-Mo steels. One of the 0.5 pct Cr-0.5 Mo steels before 10,000 hr exposure at 1050°F (565°C) had a high creep strength, but after exposure the properties were appreciably lower. Water quenching and tempering, normalizing, or annealing did not appreciably change the creep rupture strength of the 0.5 pct Cr-0.5 pct Mo steel. The ductility characteristics of the Cr-0.5 pct Mo steels are shown in Fig. 3.

In the special steels of groups VI and VII, the creep rupture strength was reduced after 10,000 hr exposure at 900°F (480°C). At 1050°F (565°C) the creep strength of the Mo-Zr steel was increased and the Cr-Mo-P steel decreased. The creep rupture strength of the phosphorus steels before exposure was high. After exposure the results were similar to the C-1 pct Mo steel. The special alloying elements did not appear to be particularly beneficial. The ductility characteristics of the creep rupture tests at 900°F (480°C) were, in general, decreased and at 1050°F (565°C), increased.

Tensile Properties

The tensile properties before and after 10,000 hr exposure at 900° and 1050°F (480° and 565°C) are summarized in Figs. 4 and 5. The yield and tensile strengths were, in general, decreased after exposure for 10,000 hr at 900° and 1050°F (480° and 565°C). The ductility in the carbon steels after exposure was increased. The tensile properties were not affected adversely by the exposure treatments.

Metallographic Results

Metallographic specimens containing the small bead weld were microscopically examined, employing conventional polishing and etching methods.

Capped Steels: Graphite ratings of the capped steels are shown in Table V. Graphite was observed in the open hearth steel after 34,000 hr exposure at 1050°F (565°C) but was not observed in the capped bessemer steel. The higher nitrogen content of the capped bessemer steel is believed to be effective in preventing graphite formation. The difference in phosphorus content between the steels is probably of little significance, and the effectiveness of nitrogen in inhibiting graphitization has been previously established.[1, 6] More spheroidization at 900°F (480°C) was visible in the capped open hearth steel than in the capped bessemer steel, although spheroidization at 1050°F (565°C) was quite complete in both steels.

Killed Carbon Steels: The graphitization of the killed carbon steels, both bessemer and open hearth, is shown in Table V. The killed bessemer steels graphitized, and thus behaved in a different manner than the capped bessemer steel. The presence of the aluminum in the killed bessemer steels, with the resultant combination of aluminum with nitrogen in the steel, has apparently been responsible for the loss of the effectiveness of the nitrogen in preventing graphitization.

It can be seen that deoxidation practice had some effect upon the amount of graphite. The killed open hearth steel 5C, which had a very small amount of aluminum content, contained no graphite in the parent metal after 34,000 hr exposure at 900°F (480°C). The straight silicon deoxidized steel 5B at 900° or 1050°F (480° or 565°C) and also the low aluminum-silicon deoxidized steel 5C at 1050°F (565°C) contained graphite. The amount of graphite was much less than in the steels containing higher aluminum.

The very low aluminum content steels 5B and 5C were not completely normal in the McQuaid-Ehn carburizing test. Fig. 6a and b illustrates that steel 5C exhibits a greater degree of abnormality compared with steel 5B. Commercial carbon steels deoxidized with silicon or small amounts of aluminum may have some abnormality in the McQuaid-

Table III. Creep Rupture Strength

No.	Exposure* and Testing Temperature, °F	Stress (1000 Psi) 1000 Hr Unexposed	1000 Hr Exposed*	10,000 Hr† Unexposed	10,000 Hr† Exposed
Group 1, Carbon Steels					
1	900	14.7	14.1	12.5	11.3
	1050	5.0	4.8	3.4	3.2
2	900	22.5	18.9	17.2	14.5
	1050	8.4	7.4	5.8	5.3
3A	900	15.8	14.6	10.8	11.0
	1050	7.3	6.8	4.9	4.8
3D	900	16.0	14.2	11.2	10.2
	1050	7.3	7.6	5.2	5.1
4A	900	15.2	13.2	10.8	9.4
	1050	5.8	5.6	3.5	3.7
4D	900	15.1	13.7	10.8	10.0
	1050	5.9	6.8	3.8	4.6
5A	900	12.9	12.3	9.4	8.7
	1050	5.8	5.4	4.0	3.7
5B	900	19.7	14.7	15.6	11.7
	1050	6.3	5.4	3.8	3.7
5C	900	18.6	13.7	13.5	10.4
	1050	5.9	5.2	3.3	3.4
5D	900	12.2	11.0	8.8	7.8
	1050	5.2	5.4	3.4	3.4
5E	900	11.8	11.4	8.5	8.6
	1050	5.7	5.1	3.9	3.5
6A	900	13.9	13.4	9.8	9.2
	1050	5.6	5.8	3.7	3.9
6D	900	13.8	12.0	10.0	8.6
	1050	5.2	5.8	3.1	4.0
6E	900	16.9	14.0	11.9	10.6
	1050	6.6	5.8	4.5	4.1
Group 2, C-Mo Steels					
7B	900	53.0	52.0	51.0	50.0
	1050	19.5	11.2	11.4	8.0
7C	900	52.0	49.5	49.0	47.5
	1050	19.5	12.9	12.2	9.8
7D	900	53.0	49.5	49.5	48.0
	1050	19.3	11.4	12.5	6.7
8D	900	69.0	62.0	67.0	59.0
	1050	21.0	15.8	11.3	11.3
Group 3, 0.5 Cr-0.5 Mo Steel					
12B	900	64.0	59.5	59.0	53.5
	1050	28.0	14.5	20.0	11.2
12D	900	65.0	56.5		51.5
	1050	19.5	12.0	10.2	8.7
12DX	900	60.0	54.5		
	1050	20.0	13.0	12.0	9.7
12DY	900	49.0	47.0		
	1050	16.5	12.0	10.2	9.2
12DZ	900	65.0	51.0	62.0	47.0
	1050	18.5	15.0	9.0	11.3
82	900	58.0			
	1050	29.0		21.0	
Group 4, 1 Cr-0.5 Mo Steels					
15C	900	51.0	45.5	48.0	43.0
	1050	18.5	14.0	11.5	11.0
	1200	6.0	4.6	3.4	3.0
83	900	56.0		48.0	
	1050	27.0		18.0	
	1200	7.4		4.3	
Group 5, Cr-Mo-V Steels					
84	900	46.0		36.5	
	1050	25.0		18.0	
	1200	7.4		4.0	
	1400	0.7		0.2	
Group 6, Cr-Mo-P-Ti Steels					
9D	900	56.0	52.0	54.5	51.0
	1050	20.2	11.5	13.9	8.5
10D	900	54.5	54.0	52.0	52.0
	1050	19.5	11.5	12.1	8.3
11D	900	58.0	51.0	57.0	50.0
	1050	19.0	13.2	11.0	10.4
13D	900	74.0	68.0	73.0	66.0
	1050	23.0	16.0	12.0	12.0
14D	900	77.0	64.0	74.0	59.0
	1050	22.0	17.0	12.0	13.0
Group 7, Mo-Zr-Ti-Cb Steels					
44	900	16.5	15.5	13.0	11.7
	1050	6.5	6.0	4.0	4.0
45	900	50.0	45.9	47.5	43.0
	1050	14.3	12.9	7.5	9.8

* Exposed for 10,000 hr without stress and then creep rupture tested.
† Extrapolated.

Ehn carburizing test. The abnormal condition of steels 5B and 5C may account for the graphitization of these steels, which had a coarse austenitic grain size. The relatively coarse grained, aluminum plus titanium deoxidized, carbon steel 6E also graphitized, as shown in Table V.

The aluminum deoxidized steels were of fine austenitic grain size and were otherwise similar to the low aluminum steels, except for the greater degree of abnormality of the higher aluminum steels. The higher carbon steels contained a greater amount of graphite.

The carbon steels had spheroidized to a great extent, and, in addition, evidence was visible in some specimens of a subcritical growth of ferritic areas at 1050°F (565°C) in portions of the weld heat-affected parent metal directly beneath the bead weld. This condition was observed and described previously.[1] The phenomenon of growth of ferrite areas apparently is associated in this investigation with welding stresses. This effect was observed in steels 4D, 5B, 5C, 5E, 6A, 6D, and to a lesser extent in steel 44. The growth of the ferritic areas did not progress to any great extent during exposure from 10,000 to 34,000 hr at 1050°F (565°C), and it appeared that this growth was virtually complete after 10,000 hr exposure. It is not known why all steels were not similarly affected, except that the deoxidation practice and chemical composition varied.

There appears to be no significant difference in the graphitization properties of killed bessemer and killed open hearth steels.

Resulphurized Steels: The graphite rating of the C-1137 resulphurized steel is shown in Table V. No evidence of graphitization was observed in the C-1118 steel, probably due to the smaller amount of carbon present. It should be noted, contrary to general practice with the free machining steels, that both of these resulphurized steels were deoxidized with aluminum. This deoxidation was necessary because the steel was melted for fabrication into seamless pipe.

Due to the fact that no great difference existed between C-1118 steel and some of the carbon steels, other than the resulphurizing, it is believed that the sulphur was effective in retarding graphite formation. Spheroidization, though not great at 900°F (480°C) for either steel, was quite complete in both steels at 1050°F (565°C). No change was observed in the appearance of the sulphide inclusions after long exposure.

0.5 Pct Cr-0.5 Pct Mo Steels: No graphite was observed in pipe samples from three 0.5 pct Cr-0.5 pct Mo steels. The steels were in the as-rolled and stress-relieved condition. It should also be noted

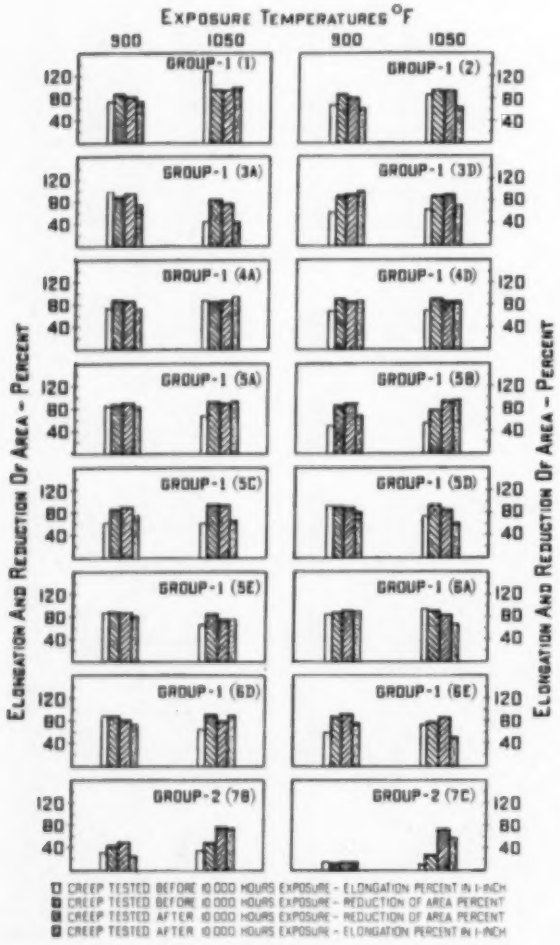


Fig. 2—Creep rupture elongation and ductility.

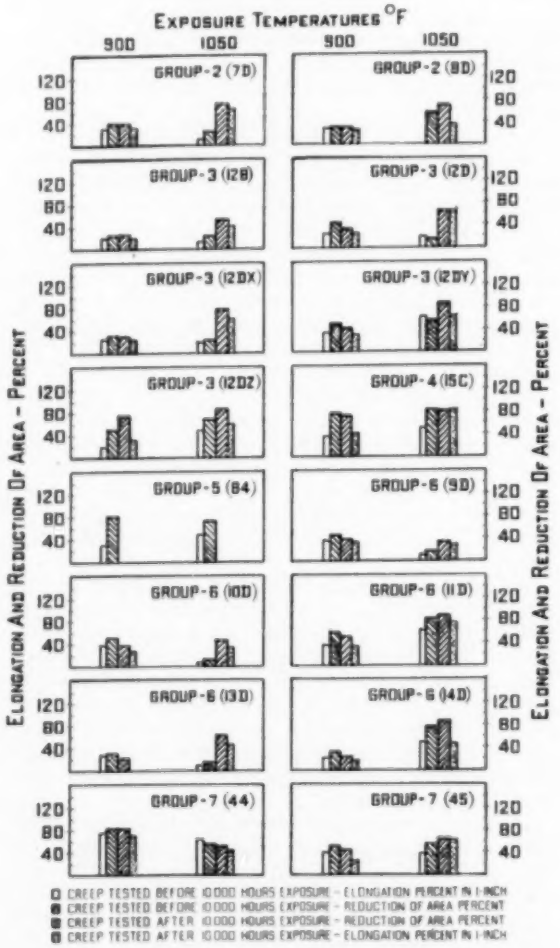


Fig. 3—Creep rupture elongation and ductility.

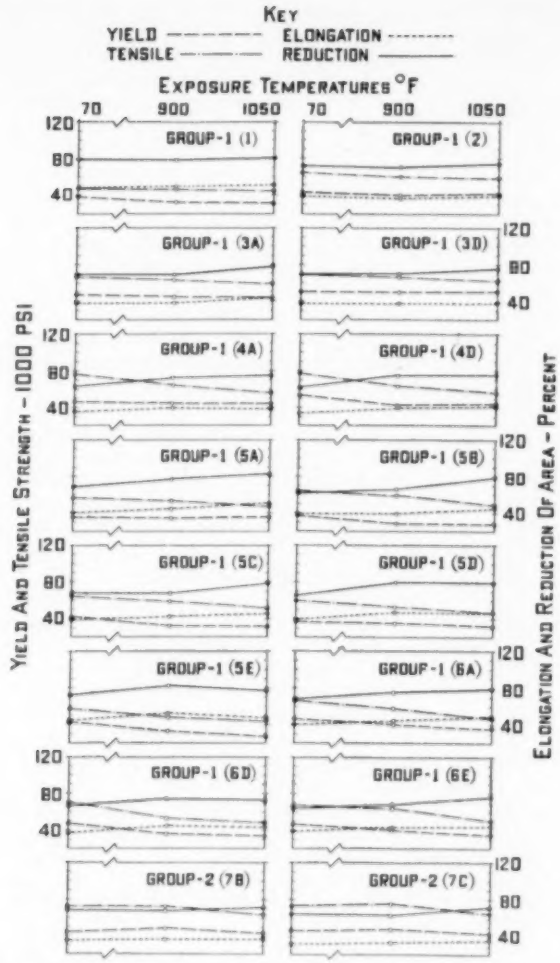


Fig. 4—Tensile properties before and after 10,000 hr exposure.

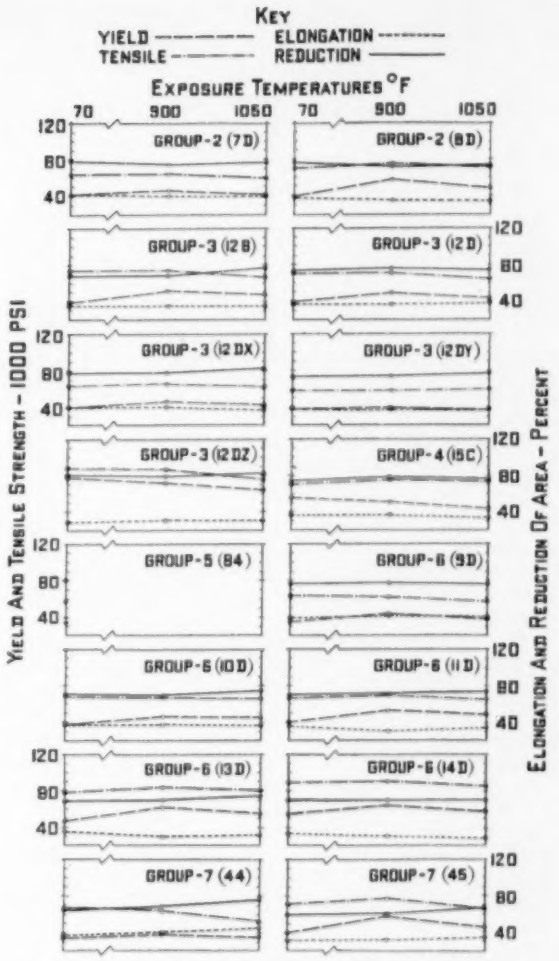


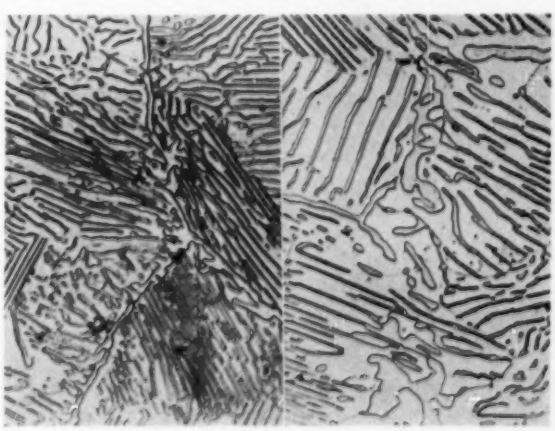
Fig. 5—Tensile properties before and after 10,000 hr exposure.

that these steels were coarse grained in the McQuaid-Ehn test. The exposure of these steels at 1050°F (565°C) may be considered an accelerated exposure test and therefore significant for steels used at a lower service temperature. The microstructures were relatively stable with a small amount of spheroidization.

High Aluminum Steels: Large amounts of aluminum were used with two induction furnace melts, one a C-0.5 pct Mo-Al steel (No. 79) and the other a C-0.5 pct Cr-0.5 Mo-Al steel (No. 80). The graphite in steel 79 is shown in Table V, with no evidence of graphite in steel 80. Although coarse grained steels have been produced with large amounts of aluminum, these steels were fine grained (Nos. 6 to 8) by the McQuaid-Ehn test and contained 0.17 pct Al. Therefore, fine grained steels can be produced with large amounts of aluminum.

A grain boundary type of graphite approaching the chain type of graphite was observed in the weld heat-affected zone of the parent metal in steel 79 exposed for 34,000 hr at 1050°F (565°C). This grain boundary type of graphite is illustrated in Fig. 7. The examination of these steels revealed that 0.5 pct Cr, even in the presence of large amounts of aluminum, is very effective in inhibiting graphite formation. These steels had a fairly stable microstructure and did not spheroidize to any extent.

Mo-V Steels: Graphitization of the Mo-V steels has been observed and reported.[1, 2] The graphitization of steels 70 and 70A after 34,000 hr exposure is shown in Table V. The addition of vanadium in these steels resulted in a fine-grained structure as



a—Steel 5B. b—Steel 5C.

Fig. 6—Carbon steel. McQuaid-Ehn carburizing test, hypereutectoid case. Picral-nital etch. X1000. Area reduced approximately 35 pct for reproduction.

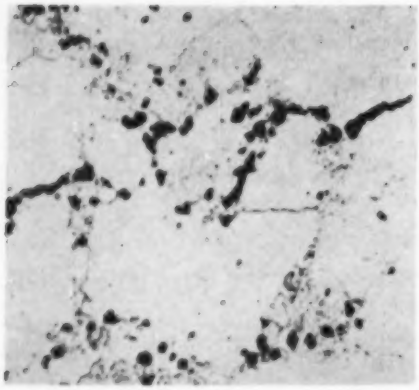


Fig. 7—Carbon-0.5 pct Mo-Al. Steel 79. Grain boundary graphite in weld heat-affected zone of parent metal exposed 34,000 hr at 900°F (480°C). Picral-nital etch. X1000. Area reduced approximately 30 pct for reproduction.

indicated by the McQuaid-Ehn carburizing test. The presence of graphite was questionable in steel 70A, and it appears that the special heat treatment was beneficial.

The presence of vanadium in the steel imparts a microscopic appearance somewhat different than the usual structure of carbon steels. The structure of the vanadium steels, particularly after the high temperature heat treatment, appears to be a dispersion of carbides within certain grains of ferrite. The structure of steel 70A (1 pct Mo-0.25 pct V) in the unexposed condition is illustrated in Fig. 8a. The manner in which the microstructure differs from the usual carbon steels is that the vanadium steels lack the lamellar-type pearlitic appearance of the carbon steels. This structural condition, for convenience, has been described as the "vanadium-type" structure.

The question of stability of the vanadium steels is of importance because of the possible creep advantages, particularly in the case of the Cr-Mo-V steels. Therefore, it is of interest to determine the structural stability upon exposure of the vanadium steels which were given the special treatment at 1925°F (1050°C) before exposure. Fig 8b depicts the change in microstructure of the 1 pct Mo-0.25 pct V steel after 34,000 hr at 1050°F (565°C). It can be seen that the carbides are smaller and more widely dispersed due to the exposure, as compared with the structure before exposure. Evidence is also visible of small unetched carbides at certain grain boundaries, and this change due to exposure may indicate to some degree lack of structural stability of the vanadium steels.

It was pointed out that the vanadium-type structure differed considerably from the usual pearlitic structure of carbon steels. A somewhat similar difference in microstructure has been observed in many of the C-Mo and Cr-Mo steels, although it does not resemble the vanadium-type structure. For convenience, the particular structure of many of these C-Mo and Cr-Mo steels has been referred to as the "molybdenum-type" structure. In the case of the molybdenum-type structure, the carbides appear to be more discontinuous and in somewhat of a Widmanstaetten-type pattern, as compared with the usual pearlite in carbon steels. The structural appearance of a commercial 0.5 pct Cr-0.5 pct Mo steel (No. 82) is illustrated by Fig. 8c.

0.5 Pct Cr-1 Pct Mo-0.25 Pct V Steels: Two different heat treatments were employed on the same 0.5 pct Cr-1 pct Mo-0.25 pct V (No. 81 and 81A) induction furnace steel. Small nonmetallic inclusions were visible in this steel but no material resembling graphite could be identified after exposure at either 900° or 1050°F (480° or 565°C) for 34,000 hr in either of the two heat-treated conditions. Here again, the presence of the 0.5 pct Cr prevented graphitization. It should be noted that this steel contained only 0.5 pct Cr, whereas regular commercial steels of this type contain 1 pct Cr. A vanadium-type structure was observed which changed during exposure to a more widely dispersed carbide structure.

Low Alloy Steels Containing Special Elements: The graphite ratings of the group of low alloy steels containing special elements are shown in Table V. No graphite was observed in any of the 0.5 pct Cr-0.5 pct Mo steels containing special elements such as phosphorus, titanium, or columbium within the limits of the tests made. Graphite was observed in

Table IV. Identification of Steels with Creep Rupture and Tensile Data not Included in Table*

No.	Type	Process†	Deoxidation, Lb Al per Net Tons of Ingots	Chemical Analysis, Pct												Grain Size		Heat Treatment‡
				C	Mn	P	S	Si	Ni	Cr	Mo	Al	N	Cu	Ti	Austenitic	Ferritic	
7B	0.5 Mo	O.H.	None	0.16	0.85	0.020	0.019	0.24	0.02	0.03	0.51	0.010	0.005	0.03	—	1-3	6-7	(1)
7C	0.5 Mo	O.H.	0.4	0.22	0.51	0.012	0.020	0.17	0.05	0.05	0.50	0.004	0.005	0.09	—	1-3	7	(1)
7D	0.5 Mo	O.H.	1.6	0.13	0.52	0.012	0.021	0.16	0.04	0.06	0.52	0.044	0.005	0.02	—	6-8	7	(1)
8D	1 Mo	I	2.0	0.14	0.45	0.021	0.014	0.16	0.03	0.01	0.97	0.048	0.006	0.06	—	20 pct 2-4 80 pct 6-8	7-8	(1)
9D	0.25 Cr-0.5 Mo	I	2.0	0.12	0.41	0.020	0.014	0.11	0.02	0.21	0.57	0.028	0.005	0.06	—	6-8	7	(1)
12B	0.5 Cr-0.5 Mo	E	None	0.13	0.51	0.010	0.015	0.22	0.04	0.48	0.58	0.007	0.012	0.03	—	1-3	5-7	(1)
12D	0.5 Cr-0.5 Mo	I	2.0	0.14	0.47	0.025	0.018	0.17	0.10	0.48	0.51	0.050	0.006	0.06	—	6-8	6-7	(1)
12DX	0.5 Cr-0.5 Mo	E	1.3	0.11	0.46	0.010	0.015	0.14	0.07	0.43	0.58	0.021	0.013	0.03	—	5-7	6-7	(1)
12DY	0.5 Cr-0.5 Mo	E	1.3	0.11	0.46	0.010	0.015	0.14	0.07	0.43	0.58	0.021	0.013	0.03	—	5-7	6-7	(2)
12DZ	0.5 Cr-0.5 Mo	E	1.3	0.11	0.46	0.010	0.015	0.14	0.07	0.43	0.58	0.021	0.013	0.03	—	5-7	6-7	(3)
15C	1 Cr-0.5 Mo	E	0.5	0.12	0.45	0.013	0.015	0.74	0.03	1.13	0.50	0.010	0.011	0.04	0.002	1-3	6-8	(4)
82	0.5 Cr-0.5 Mo	E	0.5	0.14	0.48	0.012	0.018	0.18	0.08	0.51	0.48	0.005	0.011	0.02	—	2-4	4-5	(5)
83	1 Cr-0.5 Mo	E	0.5	0.11	0.44	0.005	0.019	0.15	0.09	0.97	0.52	0.005	0.012	0.03	—	2-4	6-7	(5)
84	2.25 Cr-1 Mo	E	1.0	0.08	0.90	0.010	0.016	0.29	0.09	2.46	0.87	0.009	0.013	0.04	—	4-6	7-8	(4)

Note: Steels 12B, 12DX, 12DY, 12DZ, 82, and 83 are pipe samples; all others are forged bars.
* The graphitization characteristics of these steels were reported in previous publications.[1,2]
† O.H., basic open hearth furnace. E, electric furnace. I, induction furnace.
‡ Heat treatment prior to exposure: (1)—1650°F normalize. (2)—1650°F, furnace cool. (3)—1650°F, water quench, 1200°F draw. (4)—1650°F normalize, 1300°F draw. (5)—As-rolled pipe.

the 0.25 pct Cr-0.5 pct Mo-P steel (No. 10D) to a limited extent. The presence of graphite in a 0.25 pct Cr-0.5 pct Mo steel (9D) had been observed and reported earlier.[3] It appears that a minimum of 0.5 pct Cr should be considered for graphitization-resistant high temperature steels placed in service with the temperature range studied.

All steels of various analyses which contained a substantial amount of either titanium or columbium did not graphitize. The graphitizing effect of nickel was previously described;[1, 7] however, a 2 pct Ni steel (No. 67) containing 0.36 pct Ti did not graphitize, indicating the effect of titanium.

It should be noted that the amounts of titanium in the steels in this low alloy group were actually alloying additions. Titanium carbides were visible in these titanium steels; similarly, columbium carbides were visible in the microstructure of the columbium steels. Some chromium was present in steel 11D in addition to the 0.07 pct Ti.

Zirconium does not appear to be effective in preventing graphitization, as evidenced by the ratings in Table V for the C-Zr steel (No. 44) and the C-0.5 pct Mo-Zr steel (No. 45).

The microstructures of the steels containing special elements, except for the zirconium steels, were, in general, relatively stable. This could be expected due to the fact that many of the steels contained large amounts of stable titanium or columbium carbides.

Weld Metal: An attempt was made during examination of these steels to study the deposited weld metal to some extent, particularly with relation to possible graphite deposits. Numerous small nonmetallic deposits were visible in the weld metal. However, no deposits could be identified as graphite.

Postheating: Special postwelding heat treatments were employed in order to evaluate the effects of different heat treatments on structural stability in both the heat-affected zone and also the parent metal after exposure at 1050°F (565°C). These treatments included heating to 1300°, 1425°, and 1650°F (705°, 775°, and 900°C) for 1 hr and then air cooling, compared with the conventional 1200°F (650°C) postwelding heat treatment.

After exposure at 1050°F (565°C), only the 0.25 pct Cr-0.5 pct Mo-P steel 10D contained graphite with

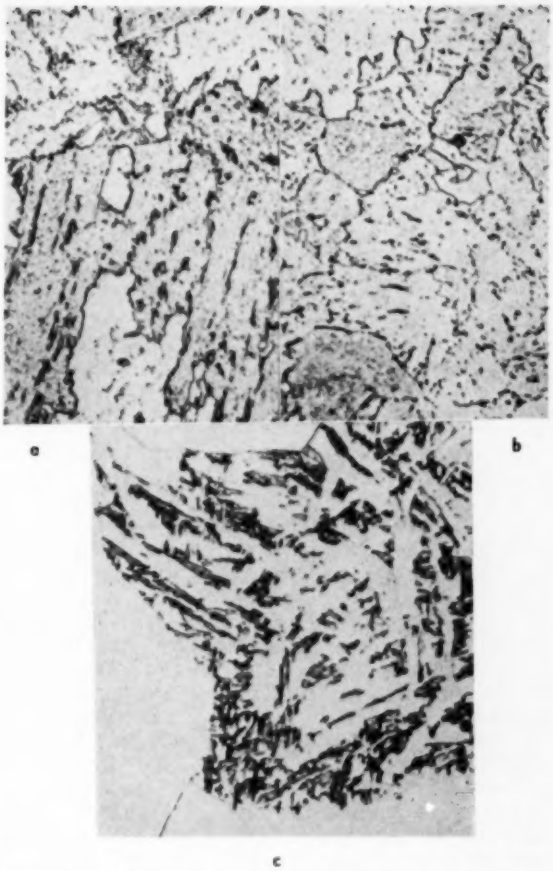


Fig. 8—Alloy steels. Picral-nital etch. X1000. Area reduced approximately 35 pct for reproduction.
a—Unexposed 1 pct Mo-0.25 pct V. Steel 70A.
b—1 pct Mo-0.25 pct V. Steel 70A exposed 34,000 hr at 1050°F (565°C).
c—Unexposed 0.5 pct Cr-0.5 pct Mo. Steel 82.

1200°F (650°C) postweld heat treatment, whereas no graphite was visible in the other samples. In the case of the 0.25 pct Cr-0.5 pct Mo-P steel, the special

Table V. Graphite Rating of Steels After 34,000 Hr Exposure

No.	Type	Process*	Deoxidation, Lb Al per Net Tons of Ingots	Graphite Ratings†							
				900°F (480°C)				1050°F (565°C)			
				(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	Capped	O.H.	Capped	0	0	0	0	3F	2E	0.4G	0.2G
3A	Carbon	B	4	0	0	0.2G	0	0	0.5G	0.7H	0.3K
3D	Carbon	B	3	0	0	5E	0.1G	0	0.2H	0.6H	0.1L
4A	Carbon	B	4	5B	10C	50B	25C	0	16E	40C	0.5H
4D	Carbon	B	3	3A	10C	25B	30B	3A	15E	18D	20C
5A	Carbon	O.H.	1.8	1F	12E	6F	0.3G	0	9F	6F	0.3J
5B	Carbon	O.H.	0	0	0	5D	1D	0	0	0.4J	0.3L
5C	Carbon	O.H.	0.4	0	3E	4F	0	0	0.1H	0.5K	0.1M
5D	Carbon	O.H.	1.4	1E	8D	115B	5F	0	6F	80C	0.6G
5E	Carbon	O.H.	1.2 lb Al, 0.3 lb Ti	0	3E	9F	5F	0.04G	0.2G	9F	0.5G
6A	Carbon	O.H.	1.4	1C	9E	8D	16D	1F	0.3J	17F	0.6G
6D	Carbon	O.H.	1.4	2F	8E	60B	30C	1F	11F	35C	22D
6E	Carbon	O.H.	0.8 lb Al, 0.3 lb Ti	0	10D	0.4G	0.2H	0	0.2H	1.2G	0.2L
41D	Resulphurized	O.H.	1.4	0	6B	10C	2E	0	2B	3D	3D
79	0.5 Cr-0.5 Mo-Al	I	4	6D	17D	70C	0	5C	60B	135B	0.3G
70	1 Mo-0.25 V	E	0.5	0	0	Trace	0	0	0	14A	2B
70A	1 Mo-0.25 V	E	0.5	0	0	?	0	0	0	?	?
10D	0.25 Cr-0.5 Mo-P	I	2	0	0	?	0	0	0	12A	0
44	C-Zr	I	16.25 lb Si-Ti-Zr	0	2E	4F	0.2J	1D	6F	0.4G	0.2J
45	C-Zr-0.5 Mo	I	16.25 lb Si-Ti-Zr	0	0	Trace	0	0	20B	100D	5F
60	C-0.5 Mo	I	2.5	0	0	8A	8A	0	0	10A	8B

* O.H., basic open hearth. B, acid bessemer. E, commercial basic electric furnace. I, laboratory induction furnace.
† (1)—Coarse zone beneath weld. (2)—Finer area beneath zone 1. (3)—Area near boundary of heat-affected zone. (4)—Parent metal.

postwelding heat treatments were effective in preventing graphitization. Samples 11D, 13D, and 14D did not graphitize.

Special postwelding heat treatments had been previously reported[8] for the 0.25 pct Cr-0.5 pct Mo steel 9D. In this steel after 34,000 hr exposure at 1050°F (565°C), only a small amount of graphite was visible in zone 3 with conventional 1200°F (650°C) postheating and no graphite was observed in the parent metal. A small amount of graphite was also observed in the special 1650°F (900°C) postwelding heat-treated bar in zone 3 of the weld heat-affected parent metal after 34,000 hr exposure at 1050°F (565°C). This would indicate that treatments of this nature will not always prevent graphitization in the heat-affected zone of a weld.

Conclusions

1—The creep rupture properties of bessemer steel after 10,000 hr exposure at 900° and 1050°F (480° and 565°C) are equivalent, and in certain instances superior, to those of open hearth steel.

2—The creep rupture strength of silicon-killed open hearth steel was superior to steels deoxidized with over 0.5 lb of aluminum per ton, but the condition was appreciably reduced after 10,000 hr exposure at 900° and 1050°F (480° and 565°C).

3—The creep rupture strength of C-0.5 pct Mo steel with different deoxidation practices was appreciably reduced after 10,000 hr exposure at 1050°F (565°C). There was no significant change after 10,000 hr exposure at 900°F (480°C).

4—The creep rupture properties of the Cr-0.5 pct Mo steels were similar to the C-0.5 pct Mo steels after 10,000 hr exposure at 900° and 1050°F (480° and 565°C).

5—Nitrogen was seemingly effective in preventing graphite formation in capped bessemer steel during a 34,000 hr exposure interval at elevated temperatures.

6—Bessemer and open hearth steels thoroughly killed with aluminum were similar in graphitization behavior. Silicon-killed steels were somewhat abnormal by the McQuaid-Ehn test and did graphitize, although to a lesser degree than the abnormal aluminum or aluminum-silicon killed steels. Graphite was observed in a relatively coarse grained carbon steel with aluminum-titanium deoxidation.

7—Coarse grained areas in the weld heat-affected zones in some steels occurred during 10,000 hr exposure, but the grain size was essentially unchanged after longer periods of exposure.

8—Sulphur retarded graphitization in C-1118 resulphurized steel. Zirconium did not appear to be effective in preventing graphitization during exposure. Titanium and columbium in the quantities used appeared to prevent graphitization. Phosphorus did not appear to influence graphitization.

9—No graphite was observed in steel which contained at least 0.5 pct Cr even in the presence of considerable aluminum. Graphite was observed in steel containing 0.25 pct Cr.

10—There was no evidence of chain-type graphite in the weld heat-affected zone after 34,000 hr exposure, but grain boundary type of graphitization was observed in several steels.

11—The 1925°F (1050°C) high temperature heat treatment of the molybdenum-vanadium steels prior to exposure appeared to aid in retarding graphitization.

12—Graphite was not observed in deposited weld metal. Special postwelding heat treatments were not always effective in preventing graphitization in the heat-affected zone of a weld.

Acknowledgment

The authors wish to express their appreciation for the assistance received from the management and operating personnel of National Tube Div. of the United States Steel Corp. They are particularly indebted to Mr. D. T. Boughner, of National Tube Research Laboratory, for tensile and creep rupture data.

References

[1] A. B. Wilder and J. D. Tyson: Graphitization of Steel at Elevated Temperatures. *Trans.* ASM (1948) **40**, p. 233.

[2] A. B. Wilder and J. O. Light: Long-Time Elevated Temperature Test of Chromium-Molybdenum Steels. *Trans.* ASM (1951) **43**, p. 323.

[3] A. B. Wilder and J. D. Tyson: Stability of Steels at Elevated Temperatures. *Steel* (Oct. 20, 1947) p. 86.

[4] D. B. Collyer and J. O. Light: Graphitization Rating Chart. *Metal Progress* (May 1949) p. 664-B.

[5] Steels for Elevated Temperature Service. *Bull.* 26 (1952) National Tube Div., United States Steel Corp., Pittsburgh.

[6] G. V. Smith, J. A. MacMillan, and E. J. Dulis: Some Aspects of Graphitization in Steels. *Trans.* ASM (1951) **43**, p. 692.

[7] A. B. Wilder and J. O. Light: Stability of AISI Alloy Steels at Elevated Temperatures. *Trans.* ASM (1950) **42**, p. 917.

Technical Note

New Technique for Preparing Homogeneous Alloys

by Pascal Levesque

IN the process of alloying two metals to obtain a single-phase alloy, the end product is nearly always a cored structure. The mechanism of solid-

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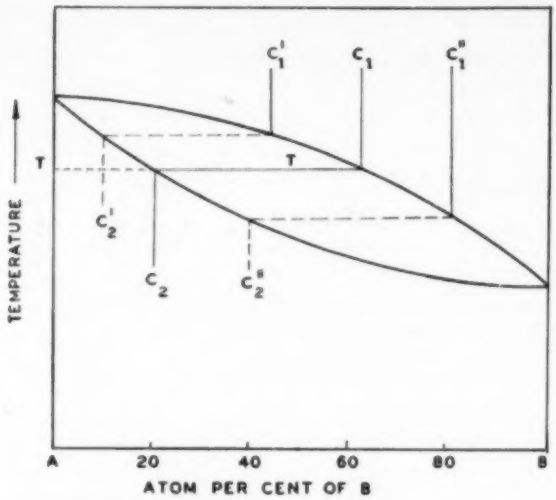

Fig. 1—Constitutional diagram of a hypothetical binary system.

ification of a liquid alloy yields successive layers of a solid phase with constantly changing chemical composition. Upon microscopic examination this solid alloy shows a dendritic segregation which results from the gradual crystallization of the alloy. By cooling the melt under the equilibrium conditions, however, a perfectly homogeneous single-phase alloy would be obtained which, upon examination, would be indistinguishable from a pure metal. The extremely slow cooling of the melt permits the homogenization of this solid structure by allowing atomic diffusion throughout the successive layers of the solid alloy and between the solid phase and the melt, but at the same time necessitates a rate much lower than is ordinarily possible.

The following technique, of special interest to the metallurgist, is an extension of work by W. G. Pfann.[1] It describes the utilization of zone melting principles to provide faster alloy homogenization by permitting the melt to freeze at constant temperature and by favoring the freezing of a solid phase invariant in chemical composition. If the liquid alloy corresponding to some composition C_1 is cooled down slowly as shown in Fig. 1, the first material to freeze out at T will have the composition C_2. As the cooling continues, the solid separating becomes richer and richer in B. If, however, a mixture of A and B of composition C_2 is added to the melt at the proper rate, then the process of solidification proceeds at constant temperature and concentration. Thus, a molten zone can be moved along a charge consisting

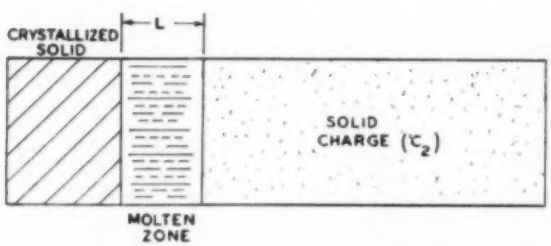

Fig. 2—Homogenization by zone melting.

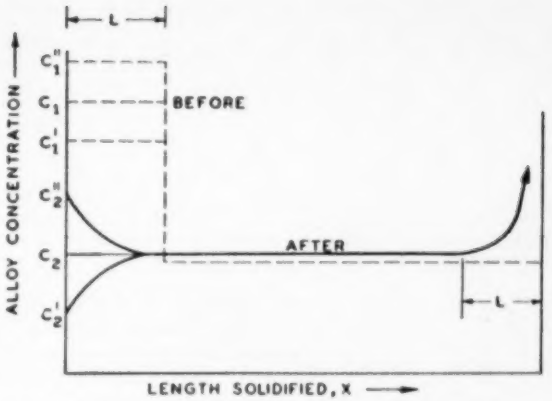

Fig. 3—Approximate concentrations before and after single pass homogenization.

of a mixture of A and B having a composition such that the process of solidification is isothermal.

The experimental technique consists in preparing two charges of concentration related by the phase diagram of the system. The initial charge might be a quenched casting, while the remainder of the boat might be a mixture of powdered constituents. The two should be separated very sharply in the loading of the boat so that the initial zone, which is going to be the molten zone, will have a concentration which does not differ very much from C_1. Slight errors in the estimation of the concentration of the initial charge may lead to C_1', for example, as shown in Fig. 1. The first crystals to separate out will then have the concentration C_2' but this will not affect the final result, since the system is self-equalizing. A schematic diagram of the process is shown in Fig. 2. Assuming that a molten zone of width L advances a distance dx in the direction of C_2, and that the cross section of the charge is uniform along the length of the boat, the total concentration in the molten zone can be expressed as

$$\overline{C}_1' L = C_1' L - C_2' dx + C_2 dx \qquad (C_1' < C_1) \quad [1]$$

where $\overline{C}_1'$ is the average concentration of the molten zone. A rearrangement of this equation gives

$$\overline{C}_1' = C_1' + (C_2 - C_2')/L\, dx. \qquad [2]$$

Thus the average concentration of the molten zone lies between C_1' and C_2, and the distance x necessary to move the molten zone before C_1' is reduced to C_1 can be calculated in specific cases. A similar treatment applies for $C_1'' > C_1$ (Fig. 1). In practice, the progress of homogenization can be followed from X-ray examinations of the crystallized alloy. Therefore it can be concluded that an error in the estimation of C_1 either on the high or low side does not affect the homogenization as long as the value of C_1 and C_2 vary monotonically with temperature along the solidus and the liquidus lines, and if C_2 in the solid charge is uniform. Those results are shown in Fig. 3 where approximate concentrations of the alloy are plotted against the length solidified for the conditions discussed above.

[1] W. G. Pfann: *Trans.* AIME (1952) 194, p. 747; JOURNAL OF METALS (July 1952).

Solid Solubility of Oxygen In Columbium

by A. U. Seybolt

The solubility limit of oxygen in columbium has been determined in the range between 775° and 1100°C by means of lattice parameter measurements and microscopic examination. The solubility is a function of temperature and varies, in the range given above, from 0.25 to 1.0 pct O, respectively.

BECAUSE of the marked deleterious effect of oxygen upon the mechanical properties of some of the transition metals, it is desirable to know something about the solubility of oxygen in these metals. The brittleness caused by oxygen in solution is particularly marked in the case of the group VA elements, vanadium, columbium, and tantalum. The solubility of oxygen in vanadium has already been reported in an earlier paper,[1] and Wasilewski[2] has given a value (0.9 wt pct) for the solid solubility of oxygen in tantalum at 1050°C.

Brauer[3] in 1941 investigated the Cb-O system up to Cb_2O_5, but made no real effort to investigate the extent of oxygen solubility in the metal. He made the observation, however, that this solubility must be less than 4.76 atom pct (0.86 wt pct) oxygen. This estimate was made from X-ray diffraction results on the alloys $CbO_{0.1}$, $CbO_{0.67}$, and $CbO_{0.86}$; all alloys consisted of the terminal (Cb) solid solution plus CbO, but the last alloy containing 4.76 atom pct O showed only three very weak CbO lines. It is surprising that Brauer, by examining only three alloys, arrived at an estimate of the solubility which agrees very well with the results to be reported herein.

Experimental Procedure

A columbium strip obtained from Fansteel Metallurgical Products was cut into strips, 0.020x½x2 in. Two holes, about 3/16 in. in diameter, were made near the ends of the strips in order to hold them against a flat steel block for mounting in a General Electric X-ray spectrometer for lattice parameter measurements. The same holes were used to hang the specimens inside a fused silica vacuum furnace tube which was part of a Sieverts' gas absorption apparatus. The apparatus and method of adding oxygen gas has been previously described.[1]

According to the supplier, the columbium obtained had the analysis given in Table I.

After degreasing the samples, approximately 0.001 in. was etched from each side of the samples in order to remove possible surface impurities from the last rolling operation. For this purpose the following cold acid pickle was found satisfactory: 8 parts HNO_3, 2 parts H_2O, and 1 part HF.

A. U. SEYBOLT, Member AIME, is associated with the Research Laboratory, General Electric Co., Schenectady.

Discussion on this paper, TP 3795E, may be sent, 2 copies, to AIME by Jan. 1, 1955. Manuscript, Jan. 29, 1954. Chicago Meeting, November 1954.

Various Cb-O compositions were obtained up to 0.75 wt pct O by the gas absorption and diffusion technique. After the sample had absorbed all the oxygen gas added at 1000°C, an additional 24 hr was allowed for homogenization. This treatment appeared to be adequate, as shown by the linearity of the lattice parameter-composition plot. More concentrated alloys were prepared by arc melting mixtures of Cb and Cb_2O_5, since it was very time-consuming to make Cb-O alloys in the neighborhood of 1 pct O, or over, by the diffusion method.

When the flat strip specimens were used, they were ready for the X-ray spectrometer after cooling from the Sieverts' apparatus. The cooling rate obtained by merely allowing the hot fused silica furnace tube to radiate to the atmosphere (when the furnace was lowered) was sufficiently fast to keep the dissolved oxygen in solution.

Arc-melted alloys were reduced to −200 mesh powder in a diamond mortar, wrapped in tantalum foil, sealed off in evacuated fused silica tubes, and then heat treated as indicated in Table II. The fused silica tubes were quickly immersed in cold water without breaking the tubes after the heat treatments. The tantalum foil prevented reaction between the fused silica and the sample; there was no reaction between the powdered samples and the foil at 1000°C, but some trouble was experienced at 1100°C. At this temperature level a reaction between the sample and the foil was sometimes observed, which resulted in erroneous parameter values.

Experimental Results

Hardness Tests: Since most of the X-ray samples were in the form of flat strip, it was convenient to obtain Vickers hardness numbers as a function of oxygen content. Compared to the V-O case,[1] oxygen hardens columbium much more slowly, presumably because of the larger octahedral volume in columbium (about 12.0Å³ compared to 9.3Å³ in vanadium), hence, requiring less lattice strain for solution. The plot of VHN vs wt pct O is shown in Fig. 1.

Table I. Columbium Analysis Given by the Supplier

Columbium	99.4 min.
Carbon	0.1 max
Tantalum	0.5 max
Titanium	0.04 max
Silicon	0.02 max
Iron	0.01 max

Table II. Lattice Parameter Data

Oxygen, Wt Pct	Lattice Parameter, A	Heat Treatment	Remarks
0.014	3.3002 ± 0.0002	2 hr, 1000°C	Oxygen content of original sheet
0.101	3.3014 ± 0.0003	1 day, 1000°C	—
0.194	0.3032 ± 0.0002	1 day, 1000°C	—
0.25	3:3042 ± 0.0003	1 day, 1000°C	—
0.294*	3.3045 ± 0.0002	16 hr, 1100°C	—
0.55	3.3086 ± 0.0005	1 day, 1000°C	—
0.75	3.3112 ± 0.0002	37 hr, 1050°C	—
2.6*	3.3125 ± 0.0004	18 hr, 1000°C	Some CbO lines
5.1*	3.313 ± 0.001	18 hr, 1000°C	Some CbO lines
3.76*	3.3049 ± 0.0007	1 week, 800°C	Some CbO lines
3.76*	3.3061 ± 0.0004	2 days, 900°C	Some CbO lines
3.76*	3.313 ± 0.001	2 days, 1100°C	Some CbO lines

* Arc melt.

Lattice Parameter Measurements: The X-ray spectrometer method yielded parameter measurements accurate to about ±0.0003Å in low oxygen alloys, but as the oxygen content increased to 0.5 pct and over, the precision dropped to something like ±0.0005Å, or poorer, in some cases. The reason for this difference is not entirely clear, but may be due in part to increased lattice strains in the solid solution. However, there are probably other factors involved, since the precision was variable in the same supersaturated alloy, given a number of different but essentially equivalent heat treatments.

Table II lists the lattice parameter measurements of the different alloys together with the heat treatments used. The same data are presented graphically in Fig. 2.

By applying the parameters found at 800°, 900°, 1000°, and 1100°C for supersaturated alloys to the curve of Fig. 2, compositions are selected corresponding to the amount of saturation at these temperatures. When these values are plotted on a logarithmic scale against the reciprocal of the absolute temperature, Fig. 3, it is found that the data fell reasonably close to a straight line. This linearity means that the Van't Hoff equation is probably obeyed, although, with only four points, the degree of agreement to the Van't Hoff relationship

$$\ln N = -\Delta H/RT + C \qquad [1]$$

is somewhat in doubt. In this equation, N is mol fraction of oxygen, or in this case, weight percent; ΔH is the heat of solution in cal per mol; R is the gas content, 1.986 cal per °C per mol; and T is the absolute temperature.

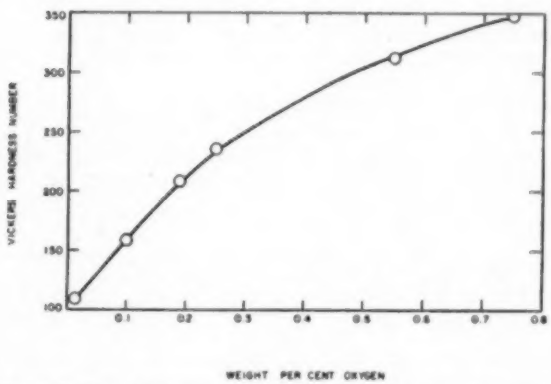

Fig. 1—Vickers hardness of columbium as a function of oxygen content.

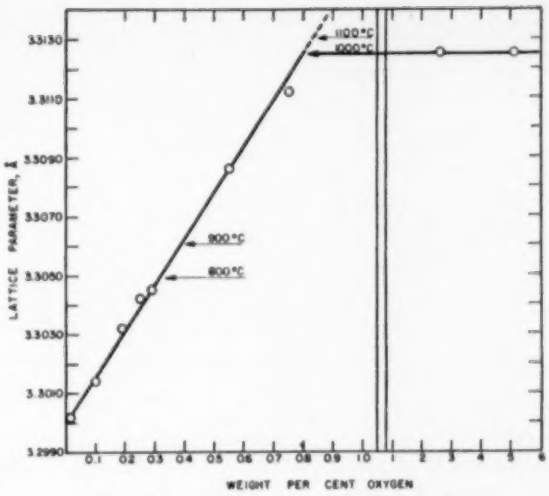

Fig. 2—Lattice parameters of Cb-O solid solutions.

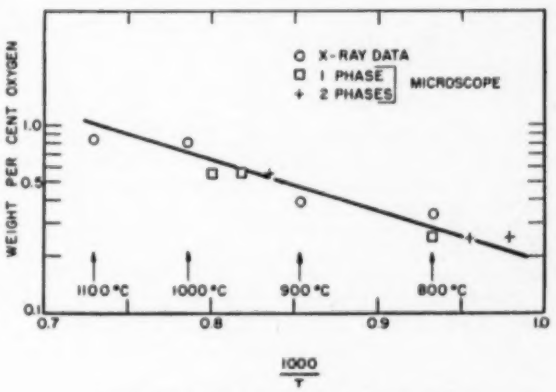

Fig. 3—Solubility of oxygen in solid columbium.

The data were plotted both as atom percent and weight percent, but in these relatively dilute solutions the closeness of fit to a straight line was the same with either method of plotting.

Metallographic Investigation: Because the accuracy of the X-ray lattice parameter measurements left something to be desired, the tentative solubility line was checked by another method. Metallographic examination was employed on two alloys containing 0.25 and 0.55 pct O. The X-ray diffraction data seemed to indicate that the more dilute alloy should be on the α/α + CbO boundary somewhere between 750° and 800°C. Similarly, the alloy containing 0.55 pct O should be at the boundary somewhere between 925° to 975°C. The heat treatments used, and the metallographic observations made, are recorded in Table III. These data are also incorporated in Fig. 3.

These results indicate agreement, within 25°C at least, with the X-ray data; hence, the line as originally drawn probably is fairly accurate. Figs. 4 and 5 show the microstructure of the Cb-0.55 pct O treated just above and just below the α/α + CbO phase boundary. It will be noted that the columbium shows a cold worked structure, indicating that at the temperature of oxygen absorption, 1000°C, recrystallization had not occurred even after 24 hr. However, the presence of cold work does not appear

Fig. 4—Cb-0.55 pct O soaked at 1000°C 24 hr to absorb oxygen, then reheated to 975°C for 25 hr, water quenched. All oxygen in solid solution. Etched in 2HF/18 HNO_3/5 glycerine. X500.

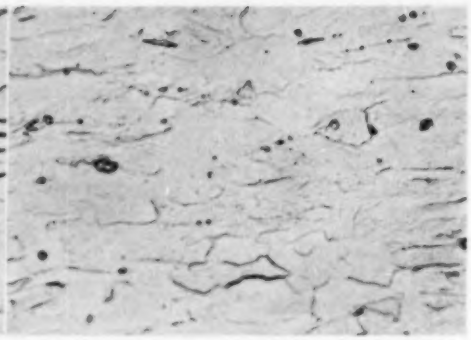

Fig. 5—Cb-0.55 pct O. Same original treatment as in Fig. 4, but reheated to 925°C for 24 hr, water quenched. Shows some CbO phase. Etched in 2HF/18 HNO_3/5 glycerine. X500.

Table III. Heat Treatments and Metallographic Results

0.25 Pct O Alloy	0.55 Pct O Alloy
4 days, 800°C, 1 phase	1 day, 975°C, 1 phase
7 days, 775°C, 2 phases	1 day, 950°C, 1 phase
8 days, 750°C, 2 phases	1 day, 925°C, 2 phases

to affect the solubility values, since an arc-melted alloy containing 0.294 pct O treated at 1100°C (see Table II) fits the lattice parameter-composition curve.

By taking the slope of the line in Fig. 3, it is found that the heat of solution (ΔH in Eq. 1) is approximately 12,500 cal per mol.

The solubility line in Fig. 6 is transposed from that of Fig. 3 into ordinary coordinates.

Effect of Oxygen Pressure Upon the Solubility Limit: While no data were obtained on the effect of pressure upon the oxygen solubility, it appears that under the conditions prevailing during these experiments, the decomposition pressure of the Cb-O solid solution was very much lower than the average pressure (10^{-5}-10^{-4} mm Hg) used in the preparation of the samples. This stability must be so, since minor variations of pressure during the vacuum homogenization of the strip samples at 1000°C or variations in time of soaking would have resulted in more or less random amounts of oxygen in solid solution.

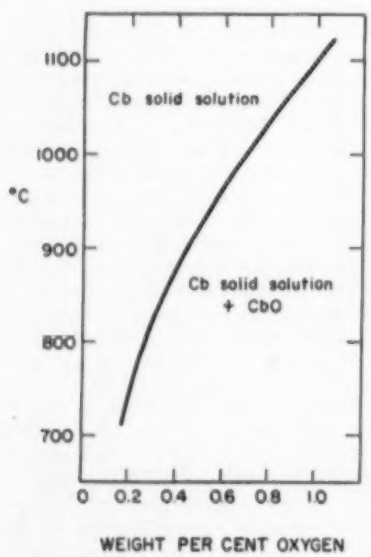

Fig. 6—Solubility of oxygen in solid columbium.

However, at some higher temperature the disassociation pressure of the solid solution becomes sufficiently great so that oxygen can be pumped out of the metal. This extraction has been demonstrated for columbium by Ang and Wert[4] who heated columbium wires to 2000°C in a vacuum of 10^{-6} mm, and thus reduced the oxygen content to less than 0.002 pct. Evidently the equilibrium pressure of oxygen over the Cb-O solid solution is greater than 10^{-6} mm Hg at 2000°C.

Similarly, R. Powers[5] has purified vanadium of oxygen by heating it to 1400°C in a vacuum of 10^{-4} mm Hg. Andrews[6] observed that in tantalum, "The dissolved oxygen . . . can be re-evolved if the filament is run in vacuum at 2200° to 2300°C." Therefore, the disassociation pressure of the solid solution places an upper limit upon the maximum amount of oxygen which can be retained in solid solution in these metals at very high temperatures during vacuum heating. Such an effect apparently has not been observed in the case of the group IVA metals.

In spite of the unstable nature of the oxygen solid solution in the group VA metals, the solubility line in Fig. 3 probably could be extrapolated safely by about 200°C in order to obtain an approximate solubility at higher temperatures.

While oxygen can be pumped out of vanadium at 1400°C, it is very unlikely that extraction at 1400°C could be done with columbium which has a much higher melting point. The melting point of vanadium is 1900°C, of columbium, 2415°C.

Acknowledgments

The author is indebted to Mrs. Ann Cooper for her work in securing the lattice parameter data, and to Miss Dorothy Kontoleon for the micrographs.

References

[1] A. U. Seybolt and H. T. Sumsion: *Trans.* AIME (1953) **197**, p. 252; JOURNAL OF METALS (February 1953).
[2] R. J. Wasilewski: *Journal* ACS (1953) **75**, p. 1001.
[3] G. Brauer: *Ztsch. anorg. allgem. Chemie.* (1941) **248**, p. 1.
[4] Chah-Yi Ang and C. Wert: *Trans.* AIME (1953) **197**, p. 1032; JOURNAL OF METALS (August 1953).
[5] R. Powers: Private Communication, 1953.
[6] Mary R. Andrews: *Journal* ACS (1932) **54**, p. 1845.

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aime NEWS

Ann Arbor Scene Of Nuclear Congress

An International Nuclear Engineering Congress under the sponsorship of the American Institute of Chemical Engineers will be held at the University of Michigan in Ann Arbor, June 20 to 25, 1954. This is the first public meeting of its size devoted entirely to the peacetime uses of the atom. Over a hundred papers and addresses will be given during the six day meeting, twelve of which are from authors in Canada, England, Belgium, France, Norway, Italy, Spain, and India.

The technical program consists of some 90 papers on the seven following subjects: Materials of Construction for Reactors, Reactor Technology, Research and Educational Reactors, Reactor Fuel Refining and Preparation, Nuclear Power Reactors, Processing of Irradiated Materials, and Applications and Uses of Radioactive Products.

Concurrent with the Nuclear Engineering Congress, the dept. of journalism of the University is sponsoring a Mass Communications Meeting. A joint session is planned on the role of the journalist in accurately communicating scientific subject material to the public.

A program for the ladies has been arranged and they are cordially invited to attend. Individuals may place their names on the mailing list for the complete program and forms for reservations by writing to Prof. Robert R. White, 2028 East Engineering Bldg., University of Michigan, Ann Arbor, Mich.

CIM Forms Hamilton Iron and Steel Branch

The Hamilton Iron and Steel Branch has been organized as a technical body aiming to serve the interests of the Canadian iron and steel industry. The Canadian Institute of Mining & Metallurgy, with its long established reputation as a professional body, serving essentially the mining industry, is being developed as the parent Institute. In Hamilton, as the center of this industry, the first branch of the CIM has been formed. It will devote itself entirely to the technical aspects of iron and steel production, fabrication, etc. Its function will be similar to the AIME Iron and Steel Div. in United States, and the Iron and Steel Institute in the United Kingdom. Through the Hamilton Branch, the CIM will identify itself more closely with iron and steel. The Institute's bulletin has been made available for the publication of technical articles.

Outline Policy On Meeting Fees For 1954

For some years the registration fees charged nonmembers of the AIME at the Conferences of the Iron and Steel Div. have been deductible on the initiation fee charged the registrant if he subsequently applies for Institute membership. This practice will continue in 1954, and the Executive Committee has voted that the same privilege may be granted for the balance of the year to registrants at all Branch and Divisional meetings provided the fee to be credited is turned over to the Institute and not retained by the Branch or Division concerned.

AIME Volumes Issued

The following volumes published by the AIME have been issued in the first five months of the year and have been mailed to those who have ordered them. Others may purchase them as long as the stock lasts at the prices mentioned:

Transactions Vols. 196, Mining Branch (1953); No. 197, Metals Branch (1953); and No. 198, Petroleum Branch (1953). $7 less 30 pct to AIME members; foreign, $7.50.

Dislocations in Metals. $5, less 30 pct discount to AIME members.

Statistics of Oil and Gas Development and Production, Vol. 7 (data for 1952). $10, less 50 pct discount to AIME members.

Ore Deposits of the Western States (Lindgren volume reprint). $7 less 30 pct discount to AIME members.

Chicago Advertising Representative Named

Robert W. Wilson has been engaged to sell advertising space in MINING ENGINEERING and the JOURNAL OF METALS from headquarters in Chicago. He is a B.S. graduate in journalism from Northwestern, with special work in advertising and business management. For nearly three years he has been with Flexonics Corp., formerly Chicago Metal Hose Corp., Maywood, Ill., for the last two years as advertising manager. His Chicago headquarters will be in the offices of the Western Society of Engineers, 84 E. Randolph St., Chicago.

Site Selected For 1957 Annual Meeting

Ample hotel space now being promised, the AIME Board has agreed to make New Orleans the scene of the 1957 Annual Meeting. The date will, however, be a week later than usual: February 25 to 28. The Mardi Gras celebration will occur the following week. The headquarters hotel has not yet been selected.

Date Changes For Metallurgical Meeting

The dates for the Joint Metallurgical Societies Meeting to be held in Europe during June 1955, have been changed. The meeting is now scheduled for June 1 through June 19. Plant visits will be made in England, Germany, and France; possibly Sweden.

ANNUAL MEETING PAPER DEADLINE

Sept. 15, 1954 is the deadline for all Institute of Metals Div. papers for the 1955 Chicago Annual Meeting and the deadline for all Iron & Steel Div., and Extractive Metallurgy Div. papers to be preprinted. Papers received by this deadline but requiring revision may not be processed in time to permit scheduling for this meeting.

Around the Sections

CONNECTICUT

The final technical meeting of the 1953-54 season of the Connecticut Section AIME was held March 10 at The Torrington Club, Torrington, Conn. Over fifty-three members and guests were present. This meeting was also the Annual Meeting of the Section. The annual reports of all officers and executive board members were received.

The nominating committee consisting of Royden S. Pratt, Chairman, Franklin H. Wilson, and Henry L. Burghoff submitted their report for officers for the coming year. The following officers were elected: Richard J. Christine, American Brass Co., Chairman; A. I. Blank, Chase Brass & Copper Co., Vice Chairman; Delmar E. Trout, Scovill Mfg. Co., Secretary-Treasurer; Frank S. Chudy, Bridgeport Brass Co., Chairman of Publicity and Attendance Committee; John D. Bervick, Olin Industries, Chairman of Membership Committee; and William E. Milligan, Yale University, Director-at-Large.

Preceding the technical session and dinner at the Torrington Club, the American Brass Co. was host to 40 members for a plant visit of the Torrington Brass Rod and Wire Mill.

A. I. Blank, new vice Chairman of the Section, served as technical chairman for the evening. The subject of the technical session was *Brass Mill Seminar*. The first talk was given by James L. Baker, metallurgist, Seymour Mfg. Co. on *Processing Phospor Bronze Rod*. The second talk was delivered by Walter Eastman, assistant metallurgist, American Brass Co., who spoke on *Function of Technical Personnel* in the Rod Mill. Richard J. Christine, American Brass Co., presented the third talk entitled *Stress Relief of Spring Wire*.

As is customary at all meetings, a technical volume was presented to someone present as a door prize, and W. D. France was the winner at this meeting.

COLUMBIA

The second annual AIME Student Meeting sponsored by the Columbia Section was held at the University of Idaho, Moscow, Idaho, on Apr. 24, 1954. This was a joint meeting with Washington State College and is held on the WSC campus at Pullman, Wash. in alternate years.

These meetings are conducted entirely by the students. The technical talks are given by the students and the student officers preside at the sessions. For the edification of the older members of the Institute it might be well to mention one characteristic that has been very evident at both of these meetings, the programs have started on time and each speech has lasted for 10 min.

The afternoon technical session was held in the Student Union Bldg. on the Idaho campus, and consisted of eight 10-min talks by four students from each school. Charles Kidwell and Conrad Pilz, the Student Chairmen for Idaho and Washington State College respectively, introduced the speakers. The topics and speakers are listed in order of their appearance on the program: *Geochemical Prospecting* by Frank P. Eno, WSC; *Iron Schist Occurrence, Freemont County, Wyo.* by Joe Paul Jemmett, I; *Replacement Monazite Deposits in Lemhi County, Idaho* by Frederick Henry Sturm, Jr., I; *New Milling Methods at the Sunshine Mine* by Harry H. Osborne, I; *Mercury Recovery at the Hermes Mine, Idaho* by Harlow H. Oberbillig, I; *Germanium in an Electrolytic Zinc Cell* by James Foreman, WSC; *Grain Growth in Copper-Aluminum Alloys* by Wallace D. Steindorf, WSC; and *Radio-Metallurgy* by Whitney G. Smith, WSC.

A banquet was held in the evening at the Moscow Hotel at which the speakers and the student chairmen were guests of the Columbia Section. About 65 members and guests were present including Roy O'Brien, Field Secretary of the AIME Western Office. There was no formal program at the banquet, and after calling the meeting to order, Chairman Kidwell turned the meeting over to L. M. Kinney, Chairman of the Columbia Section. Mr. Kinney Called on Mr. O'Brien for a short talk and introduced the other officers of the Columbia Section—F. R. Morral, Secretary-Treasurer; Norman Sather, Chairman of the Coeur d'Alene Subsection; and Roy McFarland, Membership Chairman.

Joseph Newton, AIME Faculty Sponsor of the University of Idaho, reported the activities of the Student Meeting. He stated that Rolf Morral, Secretary-Treasurer for the Columbia Section, deserves special mention for his kind interest and was in a large part responsible for the success of the meeting.

PHILADELPHIA

T. H. Blewitt of the Oak Ridge National Laboratory spoke on *Radiation Effects on Metals* during the April meeting of the Philadelphia Section, AIME.

Dr. Blewitt discussed the effects of high neutron fluxes in reactors upon the physical and mechanical properties of solids and mechanism by which these irradiation effects are introduced. These effects were illustrated by the discussion of the changes introduced in pure metals, order-disorder alloys, and age hardening alloys by both slow and fast neutron bombardment. The changes in the mechanical properties of pure metals was also discussed.

Award Established For Ferrous Metallurgy

The AIME has accepted a fund from the U. S. Steel Corp. for the establishment of the Benjamin F. Fairless Award to recognize distinguished achievement in iron and steel production and metallurgy. The Award, to be given annually, will honor the chairman of U. S. Steel for his intense interest in the technology and development of the iron and steel industry. The AIME now has distinguished achievement awards in all its major technical fields.

The following committee has been appointed by President Reinartz to draw up the rules for the Award and to decide how the Fund is to be handled: Louis R. Berner, Chairman; George T. Hanson, and Kenneth C. McCutcheon. It is planned that a suitable recipient will shortly be selected and that the first award will be made at the Annual Banquet of the Institute at the Conrad Hilton Hotel, Chicago, Feb. 16, 1955.

— Coming Events —

June 14-18, American Society for Engineering Education, annual meeting, University of Illinois, Urbana, Ill.

June 20-23, Chemical Institute of Canada, Toronto, Canada.

June 20-25, American Institute of Chemical Engineers, nuclear energy meeting, University of Michigan, Ann Arbor, Mich.

July 16-21, Joint Commission on Electron Microscopy, international conference, Senate House, University of London; London School of Hygiene and Tropical Medicine, Malet St., London, W. C. 1, England.

July 19-20, International Conference, Mechanical Effects of Dislocations in Crystals, University of Birmingham, England.

July 21-28, International Union of Crystallography, general assembly and international congress, Paris.

Aug. 23-27, Oak Ridge Summer Symposium, Modern Analytical Chemistry, Oak Ridge, Tenn.

Sept. 12-16, American Institute of Chemical Engineers, Hotel Colorado, Glenwood Springs, Colo.

Sept. 14-24, Instrument Society of America, Philadelphia.

Sept. 20-24, American Mining Congress, Civic Auditorium, San Francisco.

Sept. 24, AIME, MBD, fall meeting, Fairmont Hotel, San Francisco.

Oct. 3-7, Electrochemical Society, Inc., Statler Hotel, Boston.

Oct. 18-22, National Safety Congress and Exposition, Chicago, Ill.

Oct. 26, Assn. of Consulting Chemists and Chemical Engineers, Inc., annual symposium and banquet, Hotel Belmont Plaza, New York.

Oct. 29, AIME, NOHC and Pittsburgh Local Section, off-the-record meeting, William Penn Hotel, Pittsburgh.

Nov. 1-3, AIME, Institute of Metals Div., fall meeting, Hotel Morrison, Chicago.

Nov. 1-5, American Welding Society, Hotel Sherman, Chicago.

Nov. 1-5, American Society for Metals, National Metal Congress, Palmer House, Chicago.

Dec. 12-15, American Institute of Chemical Engineers, annual meeting, Statler Hotel, New York.

SPLITTING HAIRS

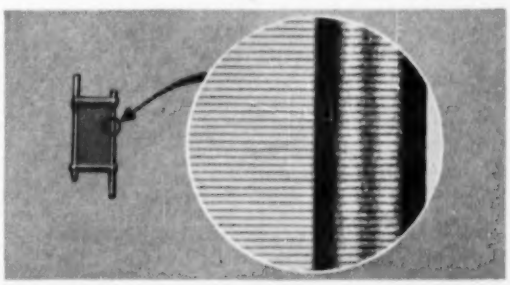
TO SPEED CALLS

This coaxial system electron tube amplifies more voices at the same time because of wider frequency band—made possible by bringing grid and cathode closer together.

To triple the voice-carrying capacity of coaxial cable, Bell Laboratories engineers had to create new amplifying tubes with the grid placed only two-thirds of a hair's breadth from the cathode. Furthermore, the grid wires had to be held rigidly in position; one-quarter of a hair's shifting would cut amplification in half.

Working with their Bell System manufacturing partners at Western Electric, the engineers developed precise optical means for measuring critical spacing insulators. On a rigid molybdenum grid frame they wound tungsten wire three ten-thousandths of an inch thick. To prevent the slightest movement they stretched the wire under more tension for its size than suspension bridge cables, then bonded it to the frame by a new process.

The resulting tube increases coaxial's capacity from 600 to 1800 simultaneous voices—another example of how Bell Telephone Laboratories research helps keep your telephone system growing at the lowest possible cost.



Grid is shown above left, actual size. Picture at right, enlarged 15 times, shows how wires are anchored by glass bond. They will not sag despite nearness of red-hot cathode.

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Hartford Scene of Eighth New England Conference

The Eighth Annual New England Regional Conference of the Institute of Metals Div., AIME, was held April 30 to May 1 at the Hotel Bond in Hartford. The Conference, under the Chairmanship of Winston H. Sharp, opened with a trip through the Pratt & Whitney Aircraft Div., United Aircraft Corp.'s plant at East Hartford. The plant tour covered the manufacture of various engine parts, testing of metals and alloys and the witnessing of a jet engine under test.

The afternoon technical session with G. R. Brophy, International Nickel Co., as Chairman included the following papers: *Large Light Metal Forging* by A. J. Pepin, Wyman-Gordon Co.; *Powder Metallurgy* by C. G. Goetzel, Sintercast Corp. of America; *Recent Developments in Rolling Metals* by N. H. Polakowski, Armzen Corp.; and *Modern Casting Practices* by F. B. Herlihy, American Brake Shoe Co.

After the banquet, Glen B. Eastburn of New York Airways, Inc. spoke on *Helicopter Operations in Metropolitan Areas.*

The theoretical session was held Saturday morning with W. A. Backofen as Technical Chairman. The papers presented were: *Fundamentals of Phase Transformations* by Morris Cohen, MIT; *Phase Transformations of Titanium Alloys* by L. S. Jaffe, Watertown Arsenal; and *Phase Transformations in Copper Alloys* by E. W. Palmer and F. H. Wilson, American Brass Co.

At the Regional Conference business meeting the following officers were elected: F. H. Wilson, American Brass Co., Chairman; K. H. Mains, University of Rhode Island, Vice-Chairman; W. H. Backofen, MIT, Secretary; and G. W. Coleman, Snell Mfg. Co., Treasurer.

A part of the Conference Committee which arranged the two day program are left to right: W. A. Backofen, MIT; R. J. Christine, American Brass Co; G. R. Brophy, International Nickel Co.; F. H. Wilson, American Brass Co.; W. H. Sharp, Pratt & Whitney Aircraft; and L. P. Tarasov, Norton Co.

Winston H. Sharp, Chairman of the Eighth Regional Conference exchanges greetings with Harrison I. Dixon, Metallurgical Products Co., who was Chairman of the First Annual Regional Conference.

The persons who participated in the Friday afternoon technical session are: standing, C. G. Goetzel, G. R. Brophy, and F. B. Herlihy; seated A. J. Pepin and N. H. Polakowski.

The authors of the papers presented Saturday morning on Transformations in Alloys are from left to right: F. H. Wilson, Morris Cohen, and L. S. Jaffe.

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No matter what you order in USS Stainless Steel, you are sure of getting a perfected, service-tested material that will give you top performance in fabrication and in end use as well.

For mill lots or warehouse quantities, call United States Steel first when you need Stainless Steel. There's a sales office near you.

PRODUCT	FINISHES	WIDTHS	LENGTHS	THICKNESSES	SIZES
SHEETS	No. 1—No. 2D No. 2B—No. 4 No. 6—No. 7	from 24" to 72"	up to 196" in cut lengths Also available in coils up to 48" (only in unpolished finishes 2B and 2D)	from .012" to .1874"	
PLATES	HR—HRA—HRA&P No. 4 Finish	over 10" to 132"	up to 480"	.1875" and heavier	
ANGLES	HRA&P		up to 360"	from ⅛" to 1½"	from ¾" x ¾" to 8" x 8"
BARS Rounds, Squares, Octagons, Hexagons	HR—HRA—HRA&P CD—RT CG—CG & Polished (Rounds only)		up to 360"		from ½" to 8⅛"
SEMI-FINISHED Blooms, Billets		from 4" to 13¾"		from 4" to 13¾"	
FLATS	HR—HRA—HRA&P CD	from ⅜" to 10"	up to 360"	from ⅛" to 2⅛"	
WIRE Coils and Straight and Cut	Copper, Lead, Tin, Galvanized, Wax, Bright, Oil, Soap, Lime		from 12" to 22'		from .008 to .500
COLD-ROLLED STRIP Coils and Straight and Cut	No. 1, No. 2	from ⅜" to 23⅛"	from 12" to 20'	from .010" to .1874"	
TUBING	Standard Pickle, Grit No.'s 80, 120, 180, 320 and rouge polishing		Comparable to other carbon, alloy cold-drawn tubing		O. D. SIZES from ⅛" to 9"

GRADES

A.I.S.I. TYPE	USS DESIGNATION
300	**SERIES**
301	USS 17-7
302	USS 18-8
302B	
303	USS 18-8FM
304	USS 18-8S
304L	USS 18-8S C.03 Max.
305	USS 18-8FS
308	USS 20-10S
309	USS 25-12
309S	USS 25-12S
310	USS 25-20
310S	USS 25-20S
314	USS 25-20Si
316	USS 18-8Mo
316L	USS 18-8Mo C.03 Max.
TS316	
317	USS 19-9Mo
318	USS 18-8MoCb
321	USS 18-8Ti
347	USS 18-8Cb
TS347	
TS347A	
400	**SERIES**
403	USS 12 Turbine
405	USS 12 AL
410	USS 12
416	USS 12FM
420	
430	USS 17
430F	
430T	
431	
440A	
440B	
440C	
442	
446	USS 27
500	**SERIES**
501	USS 5
502	USS 55

UNITED STATES STEEL CORPORATION, PITTSBURGH • AMERICAN STEEL & WIRE DIVISION, CLEVELAND • COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO
NATIONAL TUBE DIVISION, PITTSBURGH • TENNESSEE COAL & IRON DIVISION, FAIRFIELD, ALA. • UNITED STATES STEEL SUPPLY DIVISION, WAREHOUSE DISTRIBUTORS
UNITED STATES STEEL EXPORT COMPANY, NEW YORK

USS STAINLESS STEEL

4-673

SHEETS • STRIP • PLATES • BARS • BILLETS • PIPE • TUBES • WIRE • SPECIAL SECTIONS

UNITED STATES STEEL

Personals

Charles Coombs Huston is president of the Canadian Institute of Mining & Metallurgy for 1954. Mr. Huston is consultant for Macassa Mines, Ltd., Abitibi Power & Paper Co., and the Steel Co. of Canada. He is also president of Braminco Mines, Ltd., vice-president of Baltic Mines, Ltd., and a director of Amalgamated Kirkland Mines, Ltd., and Bobjo Mines, Ltd. Mr. Huston was born in Ypsilanti, Mich., and graduated from Michigan College of Mining and Technology.

R. S. Sherwin, Reynolds Metals Co., has been transferred from Sheffield, Ala., to Corpus Christi, Texas.

Henry S. Wingate, vice-president and a director, was elected president of the International Nickel Co. of Canada, Ltd., succeeding **Paul D. Merica.** Mr. Wingate was also elected to membership on the executive committee and to the presidency of International Nickel Co., Inc. Dr. Merica will continue as director and member of the executive committee and consultant to the officers of the company.

R. B. Young has been appointed plant superintendent of the Sorel operation of the Quebec Iron & Titanium Corp., Montreal Canada. Mr. Young had previously been associated with Bethlehem Steel Corp.

Chester F. Robards, formerly with the National Advisory Committee for Aeronautics, has joined the Cadillac motor car div., General Motors Corp., Cleveland tank plant, Cleveland, as chief metallurgist.

Ahmed D. Kafadar has accepted the position of manager, heat transfer thermodynamics research for the American Machine & Foundry Co., Chicago. He had formerly been at the Armour Research Foundation of the Illinois Institute of Technology.

E. R. Jerome, Jr., is metallurgist in the technical service dept., Grinnell Co., Inc., Providence, R. I. He had been with the Victor Ring Traveler Co., as assistant to general manager.

Seymour Weinstein has been appointed technical director of Niagara filters div., American Machine & Metals, Inc., East Moline, Ill. Mr. Weinstein was formerly central district sales manager for Niagara at Chicago.

H. M. Campbell has been named general manager of the metals div. and **R. A. St. Clair** has been named general manager of the electrical div., Olin Industries, Inc., East Alton, Ill.

A. D. SCHWOPE

Arthur D. Schwope has become director of metallurgical research for the Brush Laboratories Co., Cleveland. He had been a research supervisor at Battelle Memorial Institute, Columbus.

Jack Spear, formerly of the metallurgical dept., Weirton Steel Co., has organized the Economy Steel Service Co., Chicago.

Nathaniel Herz is now consulting metallurgist for Homestake Mining Co., Lead, S. Dak. He had been chief metallurgist.

James T. Gow, Sr., has been made vice-president, Sandusky Foundry & Machine Co., Sandusky, Ohio. Mr. Gow had been chief metallurgist for the Electric Steel Foundry Co., Portland, Ore.

Weston G. Thomas has been elected executive vice-president of the Climax Molybdenum Co. **Frank Coolbaugh** has been elected vice-president, western operations and **Alvin J. Herzig** has been elected vice-president, research. Mr. Thomas has been treasurer of Climax since joining the company in 1949 and was named a vice-president and member of the board of directors in 1952. Mr. Coolbaugh has been general manager in charge of western operations since December 1953. Mr. Herzig has been president of the Climax Molybdenum Co. of Michigan since 1949.

Charles Hamilton Chase has been promoted to general manager, Vulcan Iron Works, Denver. Mr. Chase had been assistant general manager. He succeeds **R. A. Fox**, who has retired but remains as a consultant.

James H. Polhemus, metallurgist, American Zinc Co. of Tennessee, Mascot, Tenn., has been promoted to assistant mill superintendent.

Thomas R. Young and **Harlow Reed** have been elected to partnership in the firm of Singmaster & Breyer, New York. Mr. Young has been with the company for nine years and Mr. Reed, eight years.

J. T. Sherman was named head of the metals process section, sales dept., Chemical Construction Corp. Mr. Sherman was formerly sales engineer for the mineral dressing dept., American Cyanamid Co., the parent company.

William J. Harris has joined the staff of Battelle Memorial Institute as a consulting scientist. Dr. Harris had previously been executive secretary of the Minerals and Metals Advisory Board of the National Academy of Science and the National Research Council. Dr. Harris has been active on the AIME Student Prize Paper Award Committee.

Emilio Jimeno of the University of Madrid, Spain, has been awarded the title of doctor in engineering, cum laude, by the Engineering College of Hanover, Germany.

William J. Welch was elected a vice-president of National Lead Co., and a member of the executive committee. Mr. Welch is a director of the company and manager of its metal dept. He has ben associated with National Lead since 1916.

T. Fujiwara is with the Imperial Chemical Industries (Japan) Ltd., Tokyo, Japan.

Raymond C. Firestone and **J. E. Trainer** were elected to the newly created positions of executive vice-president, Firestone Tire & Rubber Co., Akron, Ohio.

A. S. Kromer has been appointed general manager of the Calumet div., Calumet & Hecla, Inc., Chicago. Mr. Kromer will assume his duties at Calumet, Mich.

E. E. Schumacher, formerly chief metallurgist, has been named director of the newly created metallurgical research dept. at Bell Telephone Laboratories, New York.

Thomas H. Pattison has been appointed superintendent of operations at the Garrison plant of Mackintosh-Hemphill Co., Pittsburgh. He had been plant metallurgist since 1937. **John B. McGlade,** formerly assistant plant metallurgist has been named plant metallurgist. **Charles W. Barker** has been promoted to assistant plant metallurgist. **Oliver B. Douthett** is the new general foreman, foundry operations.

William B. Hall has been named general manager of Vitro Uranium Co., Salt Lake City, Utah.

James H. Gardner was appointed assistant director of the petrochemicals dept., National Research Corp., Cambridge, Mass.

Leland B. Flint was elected a director of Kennecott Copper Corp., New York.

R. E. McNeill, Jr., has been elected a director of the American Smelting & Refining Co., New York.

J. E. Burke, General Electric Co., manager of metallurgy, Knolls atomic power laboratory, is now research associate, metallurgy research dept., Schenectady.

H. L. Talbot has resigned as consulting metallurgist for the Anglo American Corp. of South Africa, Ltd., Northern Rhodesia and will return to the United States.

Robert Fulton has joined the Easton Metal Powder Co., Easton, Pa.

Harry O. Walp, Jr., has been transferred to the New England district office of F. J. Stokes Machine Co., Philadelphia, as senior sales engineer.

Edmond J. Silk, formerly with Sam Tour & Co., Inc., New York, has joined Babcock & Wilcox Co., atomic energy div., New York.

Clyde M. Adams, secretary of Bohn Aluminum & Brass Corp., has been appointed deputy director of the aluminum and magnesium div., business and defense services administration, Dept. of Commerce.

Frank W. Glaser was elected vice-president of the American Electro Metal Corp., Yonkers, N. Y.

William Adam, Jr., was elected president of Ajax Electric Co. **G. H. Clamer** is retiring as president, but will continue as president of Ajax Electro Metallurgical Corp., Ajax Electrothermic Corp., and Ajax Engineering Corp.

Harold C. Templeton, assistant metallurgist, has been promoted to chief metallurgist for Lebanon Steel Foundry, Lebanon, Pa. **Ray W. Patridge** has assumed the position of service manager and **Roy W. Daub** has been named chief planning engineer.

D. A. Rhoades, Kaiser Aluminum & Chemical Corp., Oakland, Calif., was recently reelected president of the Aluminum Assn. **Arthur V. Davis,** Aluminum Co. of America, New York was reelected chairman of the board.

A. T. Olsson has been appointed assistant to the sales manager of Acheson Colloids Co., Port Huron, Mich. Mr. Olsson was formerly sales engineer in Detroit.

James D. Mooney, former executive vice-president of General Motors Corp., has been elected president, chief executive officer, and a director of R. Hoe & Co., Inc. Mr. Mooney is assisting the Hoover Commission on organization of the executive branch of the government.

Eric C. Bell recently joined A. V. Roe, Canada, Ltd., Toronto, as metallurgist. He had been field engineer with Factory Mutual Engineering Div.

Choh-Yi Ang is now development section head, metals and ceramics div., P. R. Mallory & Co., Indianapolis. He had been a research assistant at the University of Illinois, Urbana, Ill.

Ray C. Reinhartsen, vice-president and sales manager, Onsrud Machine Works Inc., Chicago, has been appointed executive vice-president and general manager.

Proposed for Membership

— Metals Branch AIME —

Total AIME membership on Apr. 30, 1954 was 20,519; in addition 1401 Student Associates were enrolled.

ADMISSIONS COMMITTEE

O. B. J. Fraser, Chairman; R. B. Caples, Vice-Chairman; F. A. Ayer, A. C. Brinker, R. H. Dickson, Max Gensamer, Ivan A. Given, Fred W. Hanson, T. D. Jones, Sidney Rolle, J. H. Scaff, John T. Sherman, F. T. Sisco, Frank T. Weems, R. L. Ziegfeld.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; A, Associate Member; S, Student Associate.

Alabama
Birmingham—Pallas, George (M)

California
Fontana—Tredennick, James E. (A)

Colorado
Pueblo—Grosvenor, George A. (A)
Pueblo—Patlogar, Henry W. (A)

Connecticut
Westport—Ekholm, Lars E. (A)

District of Columbia
Washington—Maxwell, Wellwood H. (A)

Florida
Miami—Morse, Jerome G. (M)

Illinois
Alton—Akin, Paul B. (A)
Chicago—Hoff, Henry J. (M)
Chicago—Mullin, J. L., Jr. (A)
Chicago—Rosman, Morris (C/S—S-J)
E. St. Louis—Clark, Hugh L. (A)
Elmwood Park—McFarland, Richard A. (M)
Evanston—Hausner, Harry J., Jr. (A)
Harvey—Hock, John H. (A)
Homewood—Shipley, Earl H. (R. M)
Palos Heights—Heindel, Robert A. (A)
Riverdale—Johnston, George H. (A)

Indiana
East Chicago—Blumenthal, Leonard (A)
East Chicago—Kik, Frank R. (A)
Gary—Goetz, Mowry E., Jr. (M)
Gary—Kennedy, Eugene C. (M)
Gary—Ryan, Harold R. (A)
Syracuse—Clark, Jack D. (A)
Valparaiso—Warnock, George H. (M) (R. C/S—S-J)
Whiting—Cox, Charles R. (M)

Kentucky
Alexandria—Bryant, Wayne L. (A)
Ashland—Gelder, Ralph H. (A)
Covington—Hesselman, Charles B. (A)
Erlanger—Prows, Russell R. (A)

Massachusetts
Worcester—Forkum, Carl J. (A)

Michigan
Allen Park—Clark, Harry W. (A)
Detroit—Smith, Maurice J. (A)
Detroit—Trepanier, Norman W. (A)
Inkster—Specht, Oscar G., Jr. (M) (C/S—A-M)
Lincoln Park—Ferris, George A. (A)
Trenton—Lindberg, Paul E. (M)

Minnesota
Duluth—Moody, Keith H. (A)

Missouri
Clayton—Oswald, Harold B. (A)
Independence—Kuhnlein, Robert F. (A)
Kansas City—McCoy, Frederick A. (A)
Kirkwood—Persons, Norman H. (A)
Mexico—Swatek, Jack W. (A)

New Jersey
Haddonfield—Farrell, Richard E. (A)
Milltown—Dreyling, Lewis J. (A)

New York
Bowmansville—Suckow, Arthur H. (M)
Brooklyn——De Rienzo, Paul P. (J)
Buffalo—Anderson, Augustus E., III (A)
Buffalo—Arnold, Larry (A)
Buffalo—Delaney, John J. (A)
Buffalo—Hocker, Samuel M. (A)
Buffalo—Pritchard, John K. (A)
Cheektowaga—Paulus, Alfred F. (A)
Elmsford—Latiano, William D. (A)
Kenmore—Dunham, Lloyd U. (A)
Kenmore—Young, Dean S. (A)
Lancaster—Wright, Loren B. (M)
New York—Buck, Louis A. (A)
New York—Demaison, Raymond J. (A)
Niagara Falls—Arnold, William B. (A)
Niagara Falls—McFarlane, Norris B. (A)

Ohio
Boardman—Ensley, William L. (A)
Canfield—McMillan, Richard L. (A)
Canton—Keplinger, Robert B. (A)
Cincinnati—Fitzsimmons, Joseph P. (A)
Cleveland—Hauck, Alexander C. (A)
Cleveland—Macey, Herbert G. (A)
Cleveland Heights—Barrett, Harvey N., Jr. (A)
Cleveland Heights—Elliott, Samuel W. (A)
Cleveland Heights—Hruby, Thomas F. (J)
Columbiana—Leonard, Donald J. (A)
Jackson—Leone, David P. (A)
Massillon—Carpenter, Robert P. (A)
Massillon—Poth, Clarence G. (A)
Old Fort—Pence, Thomas D. (A)
Poland—Anthony, George H. (M)
Poland—Frushour, Robert H. (A)
Rocky River—Edwards, George W. (A)
Sebring—Breckner, William J. (A)
Steubenville—Spaulding, William D. (A)
Struthers—Velichko, Mike (A)
Toledo—Morse, David V. (A)
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Youngstown—Waggener, Kenneth F. (A)
Youngstown—Webb, Harold O. (A)

Pennsylvania
Aliquippa Park—Zubaly, Joseph W. (A)
Allison Park—Robinson, Willard M. (A)
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Elwood City—LaBate, Michael D. (A)
Glenside—Cass, Boyd E. (M)
Johnstown—Colbert, John W. (A)
Johnstown—Daggett, Frederick A., Jr. (A)
Johnstown—Mercill, Charles W. (A)
Johnstown—Sworb, Walter K. (A)
Library—Blocksidge, Arthur B., Jr. (M)
McKeesport—Cureton, William A. (A)
McKeesport—Scheel, Alvin J. (A)
Mineral Point—Paul, Charles M. (A)
Monongahela—Lami, Albert (A)
New Castle—Mills, Robert H. (A)
Norristown—Vallette, Joseph J. (A)
Norristown—Zimmerman, Joseph (A)
Oakmont—Tiernan, Thomas C. (A)
Philadelphia—Flegal, Russell C. (A)

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Pittsburgh—Baxter, David B. (A)
Pittsburgh—Brunner, George A. (A)
Pittsburgh—Buchanan, John H. (A)
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Pittsburgh—Topping, John (A)
Pittsburgh—Watkins, Donald N. (A)
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Sharon—Stricklin, Thomas F. (A)

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Houston—Scott, Thomas R. (A)

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Provo—Moore, Louis F. (A)
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Que., Montreal—Phelan, Michael A. (A)
St. Lambert—Ensio, Peter J. (M) (R. C/S—S-M)

Colombia
Bogota—Haieh, Patrick (M)

Japan
Nikko City, Tochigi Prefecture—Tamura, Tadao (M)

Mexico
Monclova, Coah.—Roehll, Edward C. (A)

Peru
La Oroya—Halle, Charles E. (J)

Obituaries

Benjamin Ira Eggers (Member 1937), formerly general superintendent of Globe Iron Co., Jackson, Ohio died suddenly in March 1954. Mr. Eggers was born at North Bellevernon, Pa., in 1893. He began his career as an assistant master mechanic with Pittsburgh Steel Co. at the Monessen plant. From 1914 to 1919 he held various positions with the firm. Mr. Eggers joined the Cambria Steel Co., Johnstown as assistant superintendent, blast furnaces, in 1919. For one year he was associated with the Adrian Furnace Co., Du Bois, Pa., and in 1922 joined the Trumbull Cliffs Furnace Co., Warren, Ohio. Mr. Eggers accepted the position of superintendent, Birmingham and city furnaces for Sloss-Sheffield Steel & Iron Co., Birmingham, Ala. in 1930. For three years he was general foreman of the Labelle Works of Wheeling Steel Corp. Prior to joining Globe Iron Co., Mr. Eggers had been superintendent of blast furnaces for Jackson Iron & Steel Co., Jackson, Ohio.

Karl M. Leute (Member 1940), president of Lithium Corp. of America, Inc., and also president of Manganese Chemicals Corp., Minneapolis, Minn., died on Mar. 24, 1954 at Phoenix, Ariz. Mr. Leute founded Electro Manganese Corp. in 1937. In

K. M. LEUTE

1942 he founded Metalloy Corp., which later became Lithium Corp. of America, Inc. He founded Manganese Chemicals Corp. in 1950. Mr. Leute was a member of the AIME, Electrochemical Society, American Chemical Society, and ASM.

Francis R. McNamara (Member 1949) died during January 1954. Born in Dunmore, Pa., Mr. McNamara joined the Gardner-Denver Co. in 1920 and had been continuously employed by that firm and its predecessor, Denver Rock Drill Mfg. Co. He was employed as office manager, Scranton, Pottsville, and Pittsburgh; field engineer; field engineer-sales dept. New York; district manager, Hazelton, Pa.; field engineer and Asiatic district manager, Manila; and El Paso district manager, respectively. At the time of his death, he was located at El Paso.

Albert Morris (Member 1918) died on Apr. 1, 1954 at the age of 74. Dr. Morris had been active in research, metallurgical and mechanical engineering and held more than 150 patents. He had been a consulting metallurgical engineer to Army Ordnance for 35 years. During his career he had been associated with the Cambria Steel Co., American Pulley Co., Wetherill Co., Morris Engineering Co., and Moore Drop Forging Co. At the time of his death he was residing at Springfield, Mass.

Necrology

Date Elected	Name	Date of Death
1904	John J. Blow	Unknown
1948	C. O. Denning	Feb. 12, 1954
1948	Wendell F. Hess	Apr. 21, 1954
1904	H. Hunter	Sept. 24, 1947
1903	Howard W. Throckmorton	Feb. 22, 1954
1928	William H. Whittekin	Apr. 10, 1954
1900	George J. Young	Apr. 8, 1954

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Walker & Downing

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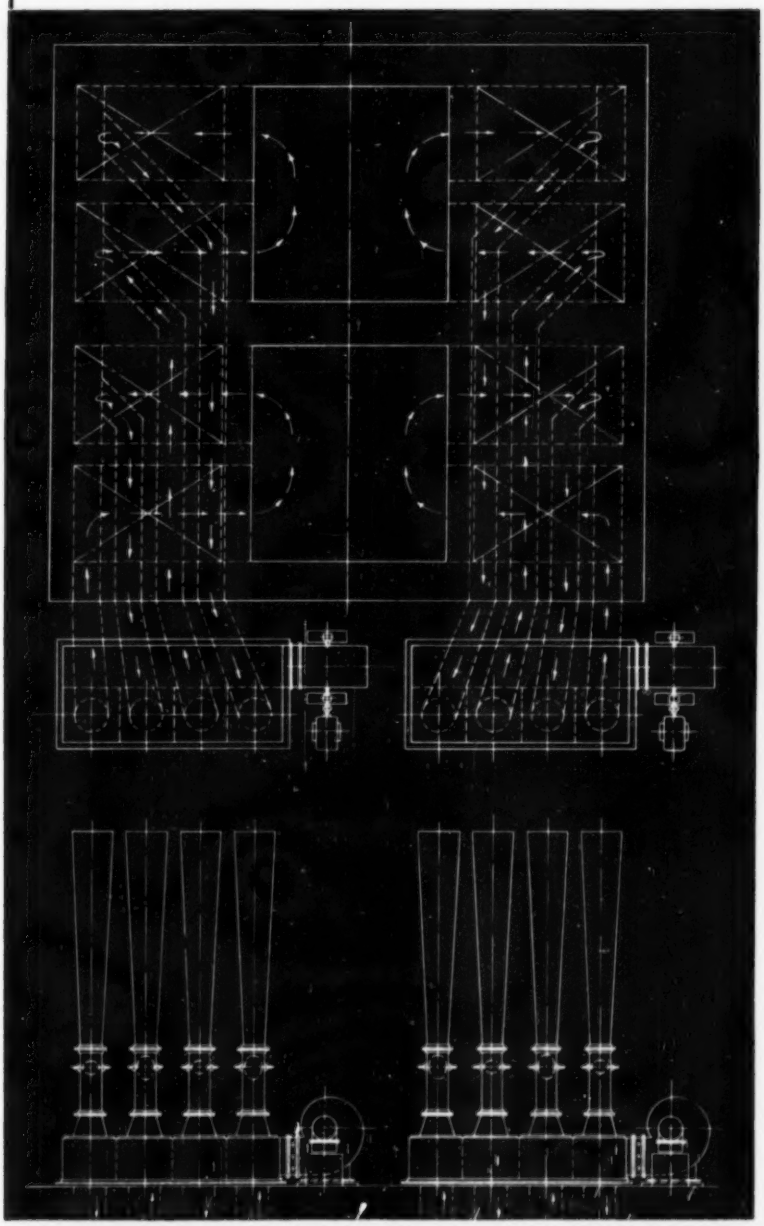

60 holes have been modernized with eight more being built now.

The Results? 35% increase in Tons per Hour per Square Foot of hearth area with resultant decrease in heating costs.

The Cost? 58% of the cost of a new one-way fired recuperative pit. This is for an entirely new installation.

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CCC-48

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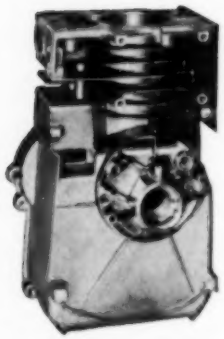
AJAX INDUCTION FURNACES

BRIGGS & STRATTON CORPORATION

1,000,000 INDUSTRIAL ENGINES

4 CYCLE BRIGGS & STRATTON GASOLINE ENGINES

With holding furnaces of 20 kW similar to that in the photo above, and melting furnaces of 100 kW, Briggs & Stratton Corp., Milwaukee, Wisc., is getting increased production under cleaner, more satisfactory working conditions than ever before, *and at lower operating costs.*



The intricate die-cast aluminum cylinder shown at the left is one of many produced at the B & S plant from high grade aluminum alloy melted in low-frequency AJAX induction furnaces. In these furnaces *only the metal is heated.* Energy is transmitted to the molten charge without actual contact through the refractory walls. There are no resistors or other parts having a higher temperature than is absolutely necessary for properly melting the charge. Overheating is avoided, and there is practically no oxidation.

The holding furnaces next to the die-casting machines as well as the melting furnaces are automatically controlled at a temperature within ±5°F., holding the metal at the lowest feasible casting temperature. The agitation due to internal electrical stirring in the metal gives the best conditions for holding furnaces, and there is little possibility of sludge formation at the bottom, because this is where the heat is generated.

Write for Further Information to

AJAX ENGINEERING CORP., TRENTON 7, N. J.

AJAX

TAMA-WYATT

INDUCTION MELTING FURNACE

AJAX ELECTRO METALLURGICAL CORP., and Associated Companies
AJAX ELECTROTHERMIC CORP., Ajax Northrup High Frequency Induction Furnaces
AJAX ELECTRIC CO., INC., The Ajax Hultgren Electric Salt Bath Furnace
AJAX ELECTRIC FURNACE CORP., Ajax Wyatt Induction Furnaces for Melting